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FINAL REPORT

HIGH RESOLUTION RADAR DATA RECORDER(U)

10 MARCH 1964

Prepared for

WESTINGHOUSE ELECTRIC CORPORATION
BALTIMORE, MARYLAND

Contract No. 86F-30-53155

GROUP-3

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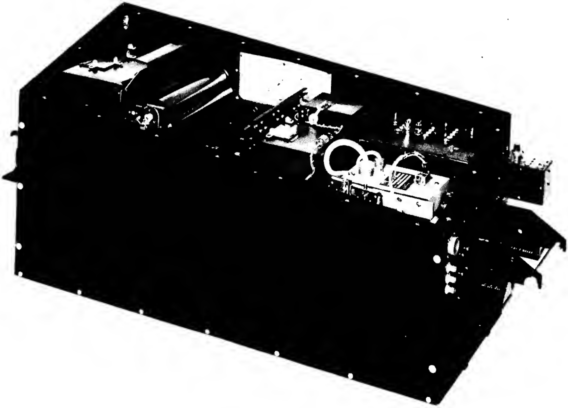

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High Resolution Radar Data Recorder—flight model

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

This final design report on the High Resolution Radar Data Recorder being developed by Itek Corporation for Westinghouse Electric Corporation (Aerospace Division) of Baltimore, Maryland, is submitted in compliance with paragraph 3.6.2 of specification PDS 21214, dated 20 September 1962.

The recorder is designed to photographically record radar video signals in the range of 2 kilocycles to approximately 40 megacycles, while preserving the signal amplitude and phase characteristics in such a manner that the photograph can be processed to obtain a positive print for data evaluation.

These requirements led to the formulation of specifications for constancy of film motion and ultimate resolution. An essentially constant film speed is necessary in retaining the phase relationships of the input signal, and extremely high resolution is necessary if the amplitude variations of the video input are to be accurately recorded as changes in film density.

The electrical design was based on the use of the Westinghouse WX4903 microspot cathode-ray tube (CRT) whose resolution has been demonstrated to be approximately 450 cycles per inch at 50 percent relative response, and 1,250 cycles per inch at 3 percent relative response.

The mechanical design was directed towards achieving the utmost constancy of film speed at the exposing plane by use of precision components and two film loops that isolate the film passing the exposure plane from the effects of supply and takeup loading.

The optical design was based on obtaining a maximum resolution capability, i.e., best attainable transformation of the electrical frequencies applied to the grid of the CRT to photographic densities recorded on the photographic film. Although the initial approach was based on fiber optics, it became evident after considerable work in this area that the fiber optics approach has serious deficiencies and, at the present state of the art, is incapable of meeting system requirements. Another approach, using conventional photographic optics in an unusual optical unfolding array, was therefore undertaken. With this system, a limiting resolution of 1,000 cycles per inch (approximately 40 lines per millimeter) was ultimately achieved.

The electronic design was centered largely upon the synchronizing and deflection circuitry required for the high resolution CRT. Transistorized circuitry was devised to provide a unique rectangular scanning technique for the 5-inch CRT. The resultant trace, when optically unfolded, presented the equivalent of a 9-inch trace to the 9½-inch-wide film. Other components required were (1) an ultrastable, very low ripple, high voltage power supply for the CRT, (2) a variable speed power inverter to drive the film capstan, (3) control circuitry for the mechanical portions of the recorder, and (4) accessory data recording equipment.

The photographic endeavor was directed towards the solution of the resolution requirements. The sensitometry of the film was explored with the aim of improving the linearity of the recording process. Each of the two optical approaches (fiber optics and conventional lens optics) presented distinct problems in selecting film whose response was optimum for the illumination available at the film plane.

Throughout the design of the recorder hardware, a "spot size reduction" program was conducted in the interest of achieving optimum resolution. Test equipment, such as a frequency modulated oscillator capable of producing patterns that would permit quick evaluation of the recorder performance, was designed, constructed, and put into service. A study was made of such unconventional CRT's as the General Electric microspot reflex-focus tube.

One of the goals of the system design was to achieve a resolution exceeding state-of-the-art capabilities. It was apparent in the early stages of the project that the CRT was a limiting factor in procuring the ultimate resolution capability. At 3 percent relative response, a CRT with a spot diameter of 0.0005 inch is capable of producing a resolution of approximately 2,000 cycles per inch. Although this resolution gives a total of 18,000 bits of information across the tube face, such a capacity is considerably less than that desired for the system. To double this capacity, a double trace generated on the 4.5-inch imaging surface of the tube face was optically formed into a 9-inch trace on the film, using a 1:1 conjugate ratio. The trace on the CRT was generated by a symmetrical, triangular current waveform which would, when applied to deflection coils, cause the spot to move upward on the face of the CRT at uniform velocity, then reverse its direction to move downward at the same rate. At each reversal in the direction of spot motion, a step function was applied to a second set of orthogonally oriented deflection coils to cause the spot to deflect sideways for its return trip. The result was a nearly rectangular scan trace approximately 4.25 inches high and 1/4 inch wide.

In the first three recorders, an unfolding fiber optics array was placed in contact with the fiber optics face of the tube. In recorders 4 through 7, a lens and mirror system was used to unfold the trace. The two long sides of the trace on the CRT were transmitted through the unfolding array in such a manner that at the output end the trace was a continuous 9-inch display similar to that developed optically in subsequent versions of the recorder. The ends of the fibers were polished so that 9.5-inch-wide film could be pulled across them in contact with the trace image.

During the design and development program, three fiber optics recorders and three standard optics recorders were delivered. A seventh recorder of essentially the same configuration as the sixth recorder, but incorporating refinements suggested by studies and evaluations made to date, is being constructed for use in the design evaluation program.

The design of the first three recorders assumed the ultimate availability of satisfactory fiber optics. Since this goal was never achieved, these recorders were conditionally accepted by the customer without their fiber optics assemblies. The delivery of the remaining units was constantly hampered by the nonavailability of CRT's of 1/2-mil spot diameter and by problems with their high voltage power supplies. The average CRT to date has a spot size of 0.00067 inch.

2. SYSTEM DESCRIPTION

The High Resolution Radar Data Recorder (see Fig. 2-1) is one of several equipment items comprising radar set AN/APQ-93 (XA-1). The recorder accepts video input signals from the radar and, by means of suitable optical, photographic, and electromechanical systems, delivers an output film on which the amplitude and phase variations of the radar video appear as density variations in the emulsion. (Tables and figures are presented at the end of this section.)

The recorder package is 47 inches long, 14½ inches wide, and 19½ inches high. Its weight, including 500 feet of thin base (3-mil) or 250 feet of thick base (5.5-mil) Eastman Kodak Plus-X film of 9½-inch width, is approximately 185 pounds. Four shear-type vibration isolators having a natural resonant frequency of approximately 3 cps support the recorder.

The radar video from the AN/APQ-93 enters the recorder through a customer supplied video amplifier mounted at one end of the recorder structure. The amplified signal is then applied to the control grid of a Westinghouse WX4903P11 CRT having a 4.5-inch-diameter imaging area. CRT sweep and blanking are controlled by suitable deflection and logic circuits that are triggered by 4-, 8-, and 16-kilocycle pulses from the aircraft radar control system. Correction for deflection defocusing is accomplished by a dynamic focus modulator that impresses a paraboloidally shaped output waveform on the 4-kilovolt potential of the CRT's focusing electrode. This voltage, as well as the 15 kilovolts for the ultor and the 500 volts for the accelerating anode of the CRT, is generated by the high voltage power supply in the recorder. The other voltages required by the recorder (115 volts, 400 cycle; + 300 vdc; ±150 vdc; ±60 vdc; ±27 vdc; ±24 vdc; and ±12 vdc) are taken directly from the aircraft supplied voltage inputs, or are zener regulated from them down to the required level.

The combined action of the recorder's triangular sweep and step deflection circuits generates a 4.25-inch-long, 1/4-inch-wide rectangular pattern whose long dimension is vertically oriented on the face of the CRT. This pattern is unfolded by two parallel optical channels in such a way that the two long sides of the sweep trace are joined end-to-end at the imaging surface (i.e., where the film passes an exposing slit at the capstan). Variations in the amplitude of the video input signal produce corresponding density variations along the 8.5-inch-long trace.

Since the film is transported through the recorder at a rate that is precisely synchronized with the aircraft's ground speed, the resultant photography is a graphic presentation of signal amplitude as a function of (1) the rotation of the line of sight from aircraft to target, and (2) the target range.

The description of the recorder will be more easily followed if reference is made to (1) the cutaway perspective drawing of Fig. 2-2, which shows the approximate physical relationships of the film transport system, the optical system, and the various electronic assemblies, and (2) to Fig. 2-3, a functional block diagram of the entire system. In the following discussion, references to the "right" and "left" sides of the equipment assume the observer to be standing at the end of

the recorder containing the data projector and the takeup spool. The right side supports the motors, pulleys, and other active components of the film transport system.

The major elements of the structure enclosing and supporting the various components of the recorder are two aluminum sideplates which, after machining, are joined by structural tees, welded-up braces, and the main supporting members of the optical system subassemblies. Each plate has a cutaway section that accepts an Invar plate of the same shape as the removed section. These plates directly support the various optical assemblies and, due to Invar's extremely low coefficient of expansion, prevent unacceptable variations in the length of the optical path.

The strength-to-weight ratio of the recorder structure is maximized by lightening holes milled in the sideplates wherever feasible.

Aluminum covers which attach to the basic structural plates and to each other prevent the admittance of any stray illumination.

Loading and threading of the film can be accomplished by removing the top cover only. Troubleshooting and repair are accomplished by removing the side covers as well. The removal of major components, when necessary, is facilitated by the removal of the bottom cover. A removable panel at one end of the recorder permits access for purposes of focusing the trace on the capstan.

Table 2-1 list the weights of recorder components.

2.1 OPTICAL SYSTEM

The optical system (see Fig. 2-4) comprises a reflecting prism, two V-mirrors (each designated as M1 in the figure), two lower mirrors (M2), two Wollensak 6⅜-inch-focal-length Raptar lenses having an f/2 relative aperture and adjustable iris diaphragms which permit the lenses to be stopped down to f/11, and two adjustable mirrors (M3).

As seen in the diagram, the illumination from each of the parallel vertical traces on the face of the CRT impinges on one face of the prism and is reflected laterally, at an angle of 90 degrees, to one of the M1 mirrors with an accompanying 90-degree rotation of the trace about the optical axis. As a result, the two traces are given the desired end-to-end orientation. The trace reflection from each of the M1 mirrors is directed downward to the associated M2 mirror and thence to the associated lens. After emerging from the lens, the trace image in each optical channel is reflected (by mirror M3) toward the exposure slit in the image-plane light stop. The two M3 mirrors are adjusted until the desired 1:1 projection (in good focus) is achieved at the film plane. The focusing adjustment is accomplished by means of a lead screw for each mirror. As the screw is turned, the mirror assembly moves in a direction that is parallel to the optical axes of the lenses. Each mirror is mounted on a plate that rotates about a hardened steel ball and stud; the ball and stud are held in a socket of the supporting casting by means of a spring washer and elastic stop nut. Each of the adjustable mirrors can be tilted about a horizontal axis in order to direct the trace image into the exposure slit, and can be rotated about a vertical axis in order to bring the ends of the image into optimum focus.

Fig. 2-5 is a photograph of the prism, V-mirror, and M2 mirror assembly; Fig. 2-6 shows the lens and M3 mirror assembly. The reflective surfaces of all the mirrors in the main optics of the recorder are optically flat to a tolerance of 1/8 wavelength, are aluminized, and are overcoated with a protective layer of silicon monoxide. Behind each mirror are three nylon-tipped set screws that are tightened until the edge of the reflecting surface is properly registered against opposing locating clips. This mounting arrangement facilitates the servicing and, if necessary, the replacement of any of the mirrors.

In addition to its main optical system, the recorder incorporates two secondary optical systems: (1) a data projector assembly and (2) a trace viewing assembly.

2.1.1 Data Projector Assembly

The data projector assembly (see Figs. 2-7 and 2-8) provides the means for exposing (1) a reduced scale (5.1:1) image of a 24-hour watch, and (2) the alphanumeric characters on a data card, onto one edge of the $9\frac{1}{2}$-inch-wide film. In addition to the card and watch (which comprise the so-called data block), the data projector assembly includes (1) a 44-mm, f/3.5 lens, (2) two mirrors, (3) two flash tubes that are fired simultaneously every 10 seconds, and (4) two high voltage transformers which provide the firing potential. The timing circuitry for the data projector is discussed in Section 2.4.8.

To ensure an adequate exposure and depth of focus, the lens aperture is normally set at approximately f/11 by means of the iris diaphragm. Screwdriver adjustments for aperture and focus settings are provided.

2.1.2 Trace Viewing Assembly

The trace viewing assembly (see Fig. 2-9), an auxiliary item* for the recorder, is shipped in a separate wooden storage case. When installing this assembly, it is necessary to remove the takeup cassette and the takeup light baffle. Four captive screws, two at each end of a carriage mechanism, are used to secure the assembly to the recorder.

The assembly consists of a Bausch and Lomb microscope with 32-mm objective, two interchangeable eyepieces (5× and 10×), two mirrors on a turret mount, and the carriage which supports these items while permitting them to be moved manually as an integral unit for examination of various portions of the trace.

A conventional rack and pinion mechanism permits focusing of the microscope by means of a thumbscrew, and the distance between the objective and the two mirrors can be easily adjusted by rotating the mirror turret on its threaded coupling. The two mirrors can be individually tilted to effect the desired optical alignment.

The smaller of the two mirrors is used when viewing the trace image on the capstan; the larger mirror permits viewing of the aerial trace image projected by the lens. The smaller mirror measures 13/16 by 7/8 by 1/8 inch and the larger mirror 1 by 3/8 by 3/8 inch.

2.2 PHOTOGRAPHIC SYSTEM

The photographic system (see Fig. 2-2) is designed to drive the $9\frac{1}{2}$-inch-wide film past a narrow slit through which the CRT trace is imaged on the film as it is moved by a metal capstan roller. Two prime requirements are that the film move with extremely smooth velocity and, at the imaging area, be isolated as much as possible from vibrations originating in the recorder itself and/or the aircraft in which it is to be installed.

2.2.1 Film Transport System

The film transport system comprises (1) similar light-tight supply and takeup cassettes (see Fig. 2-10), the former having a sensing arm and geared potentiometer for energizing a remote film supply indicator, (2) two torque motors which maintain the required film tension at the reels in order to prevent spin off, (3) a supply drive roller assembly and a takeup drive roller assembly, each driven through planetary reduction gears by a separate 28-vdc, 0.15-ampere motor, (4) a viscous drag roller assembly, (5) a capstan roller assembly, (6) a belt and pulley speed reduction system, and (7) a 6,000-rpm, 115-volt, 400-cycle, synchronous, main drive motor. Fig. 2-11 is a simplified mechanical drawing showing the film path through the recorder.

*Not used in system operation.

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The rate at which the film is moved past the exposure slit is a function of aircraft ground speed. A speed control assembly (see Section 2.3.9) is used to provide an excitation voltage for the synchronous, main drive motor; the frequency of this voltage is, at any given time, proportional to ground speed, but is variable over a range of approximately 350 to 450 cps. At the midrange speed of 400 cps, the speed of the synchronous motor is 6,000 rpm. The speed reductions (3.52:1, 8:1, and 8:1) provided by the three-stage speed reduction system combine to produce a capstan speed of 25.46 rpm (film velocity of 2 inches per second) at the nominal input frequency of 400 cps. The capstan drive roller assembly provides the controlling drive force for film transport. The purpose of the supply and takeup drives is to generate a slack loop ahead of, and after, the exposure slit. These loops effectively isolate the motion of the film (at this point in the film path) from the effects of supply and takeup loading. The length of each slack loop is held relatively constant by an on/off controller in which a wire finger opens or closes an associated microswitch as the size of the loop increases beyond a predetermined value. The microswitches control the speed of the supply and takeup drive motors as necessary to maintain the desired loop length.

The two torque motors at the cassettes gear-drive their associated film spools in opposite directions. The supply reel torque motor provides a moderate force which, by opposing the film motion imparted by the supply loop drive roller assembly, prevents the film from unwinding too fast. The takeup reel torque motor causes the film at the takeup cassette to be wound at a rate which prevents the formation of a slack loop at the output of the takeup drive rollers.

The sensor for the remote film supply indicator (a 1-milliampere meter with 12-kilohm series resistor) is a Rulon arm which rides on the film of the supply cassette and is geared to a servo-type, 500-ohm potentiometer having 325 degrees of travel. When the supply reel has a full load (250 feet of thick base or 500 feet of thin base film), the remote film supply indicator will register a full scale (12-volt) deflection. When the film in the supply reel is depleted, a switch (mounted near the metering arm) causes the main film control relay to open and the film transport to stop. The metering arm must be swung free when inserting a film reel into the cassette.

2.3 ELECTRONICS SYSTEM

The electronics system of the recorder consists of 12 assemblies whose locations are shown in Fig. 2-2. These assemblies are:

1. Deflection and logic
2. Step scan
3. High voltage power supply
4. High voltage time delay
5. Focus modulation coupling
6. CRT automatic brightness control and CRT brightness malfunction indicator
7. Bias control
8. Data flash
9. Speed control
10. Loop control
11. CRT
12. Video amplifier (customer supplied)

In addition to these main assemblies, there are three component boards (for CRT protection, ±60-volt decoupling, and CRT acceleration-anode decoupling) which are not shown in Fig. 2-2. These boards are mounted on the sideplates of the basic recorder structure.

2.3.1 Deflection and Logic Assembly

Fig. 2-12 is an external view, and Fig. 2-13 is a functional block diagram, of the deflection and logic assembly. This assembly, which occupies a space measuring 6 by 9 by 8 inches, includes the following circuits: (1) triangular scan generator, (2) scan malfunction detector, (3) high voltage driver, (4) CRT dc heater supply (5) film motion detector, (6) CRT sweep centering, and (7) dynamic focus modulator. The synchronous signal inputs to the deflection and logic assembly are three 40-nanosecond, 10-volt pulses at approximately 4, 8, and 16 kilocycles from the customer's equipment.

Triangular Scan Generator

The scan generator circuits are seen in Fig. 2-13. The following functions are performed:

1. Generation of a symmetrical, triangular current waveform which when applied to the vertical deflection coils causes the CRT beam to sweep in a linear manner. This sweep is alternately upward and (after a lateral step deflection) downward over a distance of 4.25 inches on the face of the tube, in step with the radar's 8-kilocycle pulse repetition frequency. A symmetrical square-wave current applied to the horizontal deflection coils produces the lateral deflection.

2. The generation (by the blanking flip-flop multivibrator) of a 4-kilocycle square wave that is applied to the high voltage driver circuits (see the high voltage driver discussion of this section) and to the blanking amplifier. The purpose of the blanking signal is to cut off the CRT beam during that portion of the radar's operating cycle when recording is not desired.

As shown in the block diagram, the triangular waveform circuits of the scan generator consist of a bistable multivibrator, a buffer emitter follower, and a sweep generator. The approximately 8-kilocycle trigger causes the multivibrator to alternately conduct and cut off in a sequence that generates a square-wave current of the same frequency which controls the frequency of the triangular sweep generator. The output of this generator is supplied to the horizontal deflection coils of the CRT to step the trace laterally.

The deflection waveforms must be synchronized with the input pulses in order to ensure that the CRT trace is properly phased with respect to the input video. Fig. 2-14 shows the system's waveform relationships. Fig. 2-14a shows the 4-, 8-, and 16-kilocycle input pulses supplied to the recorder by coaxial shielded cables through BNC feedthrough connectors on the external skin. Fig. 2-14b shows the output of the main deflection flip-flop. Since PNP transistors are used in this part of the system, the output waveform is an 8-kilocycle, negative going square wave synchronized with the 8- and 16-kilocycle pulses; these pulses have an amplitude of 10 volts, a width of 40 nanoseconds, and are from a source impedance of 50 ohms. The input flip-flop uses 2N781 transistors to trigger on these very fast timing pulses. The 4- and 8-kilocycle pulses are fed to the blanking flip-flop and thence to the blanking amplifier; the latter supplies a +60-volt, 4-kilocycle square wave to the CRT cathode to effectively blank the display during the off portion of the video waveform.

The output of the main 8-kilocycle flip-flop is coupled through an emitter follower and thence to a 2N1670 transistor which serves as a voltage amplifier that drives the triangular deflection and step deflection circuits in synchronism. This 8-kilocycle rectangular waveform drives a phase inverting current transformer which alternately switches two 2N1552 power transistors on and off. These transistors switch the voltage on the storage capacitors across a 0.75-millihenry, 0.75-ohm coil for scan deflection. The current in this coil builds up in an approximately linear manner to form a triangular scan current waveform.

Scan Malfunction Circuits

The input to the scan malfunction circuit is a 60-volt peak-to-peak square wave from the scan

generator. At the 0.75-millihenry triangular-deflection coil, this signal is converted to a dc level by a 1N458 diode. Diode output is amplified by a 2N1670 transistor whose output energizes a 10,000-ohm relay. In the event of a scan failure, the relay drops out to short the 500-volt first anode potential of the CRT to ground and thereby prevent a phosphor burn. The high output impedance of the 500-volt tap on the high voltage supply prevents any damage to the supply when this shorting occurs. The loss of illumination as a result of scan malfunction energizes the NO-LIGHT indicator of the ABC circuit.

High Voltage Driver

The high voltage driver uses a single transistor to amplify the 3.92-kilocycle square-wave output of the blanking flip-flop to a negative going square wave of the same frequency and −10-volt amplitude. This square-wave signal is more than adequate to lock the dc-to-ac converter to the 3.92-kilocycle signal. To prevent degradation of the CRT trace, the driver is so designed that any ripple components from the supply are synchronized with the sweep waveform.

CRT DC Heater Supply

The CRT dc heater supply uses a bridge rectifier, RC filter, and a zener diode and power transistor regulator to convert a 115-volt, 400-cps input voltage to a low ripple output that is closely regulated to 6.3 vdc at currents up to 1.2 amperes, and provides heater power for the 6U8 tube in the focus modulator as well as that for the CRT. (The normal drain on this supply is on the order of 900 milliamperes.)

Fig. 2-15a is a schematic of, and Fig. 2-15b is the equivalent circuit of, the heater supply. The regulator portion of the supply includes R1, R2, the transistor, and the diode—the latter establishing the base bias in the emitter follower transistor stage. As the load voltage, V_L, decreases, the base-to-emitter voltage, V_{be}, increases, because their sum is V_Z, the constant zener voltage. The increase in V_{be} increases the conductivity of the transistor and returns the load to its nominal value. This type of circuit effectively amplifies the zener diode's power handling capability, since only 10 percent of the load current flows through the diode. The ripple reducing effectiveness of this circuit is due to the low ac impedance of the zener in combination with the power transistor.

This supply is extremely stable, and has good regulation under both line and load variations. It provides regulation and filtering on an order that is difficult to achieve at low voltages and high currents. Although somewhat complex for the relatively simple function performed, the supply can be justified in terms of its high reliability and relatively low weight and size.

Film Motion Detector

The film motion detector utilizes a variable reluctance pickup that is electromagnetically energized by the motion of each tooth on a 60-tooth gear (see Fig. 2-1b) driven by the viscous drag roller. The 50-millivolt peak-to-peak signal from the transducer has a frequency of approximately 11 cps at nominal (2 inches per second) film speed. This signal is amplified, detected, and used to drive a following relay driver stage to full conduction. A relay in the collector circuit of the driver is deenergized if the film drive viscous drag roller ceases to turn, and causes the film motion malfunction indicator to light.

The pickup head is mounted 0.005 inch from the 60-tooth gear. Sensor output is amplified by a 2N398A transistor operating at a dc collector current of approximately 4 milliamperes and having a gain of 40. A second (relay driver) 2N398A, in combination with a 1N458 diode, clamps the amplified signal at a proper negative level. This transistor is operated as a switch in order to hold the film motion relay closed during normal operation. The 180-microfarad capacitor (C2325) removes the high ripple content from the voltage applied to the relay (K2304), and the

shunt diode (CR2318) aids in discharging this capacitor rapidly when the relay driver is cut off due to no film motion.

Sweep Centering Circuit

Sweep centering is accomplished by two 1-kilohm potentiometers connected in a series-parallel arrangement with four fixed resistors having + 60 volts and −60 volts applied at the opposite ends of the parallel combination. One of the potentiometers provides for the up/down centering of the trace on the CRT; the other potentiometer provides for right/left centering adjustments.

Dynamic Focus Modulator

The function of the dynamic focus modulator circuits (see the block diagram of Fig. 2-13) is to generate a paraboloidal voltage waveform which combines with the nominal 4 kilovolts applied to the focus electrode of the CRT in such a way as to correct the focus of the CRT as a function of the deflection angle during scan. The input to the modulation is an 8-kilocycle, negative going square wave of 8-volt potential supplied from the emitter follower of the sync flip-flop in the scan generator. The modulator converts the square wave to a synchronized sine wave; the sine wave is amplified and rectified to obtain a 140- to 160-volt peak-to-peak output that is precisely phased with the 8-kilocycle vertical-sweep waveform and is capacitively coupled to the focusing anode of the CRT through the focus modulation coupling assembly (see Section 2.4.5).

Fig. 2-16 is a schematic of the dynamic focus modulator. As is seen, transistor Q2325 is an emitter follower which buffers the sync flip-flop from its several loads—one of these being the focus modulation circuits. The input square wave from the emitter follower is applied to transistor Q2310 working as an inverter and driving an LC tuned circuit which shapes the 8-kilocycle input square wave to a wave of the same phase and frequency as the input signal. Q2311 is an emitter follower buffer stage which prevents loading of the tuned circuit. The sine wave is ac coupled to Q2312, an amplifier having ample emitter-to-base and collector-to-base negative feedback. To obtain the highest possible gain, Bendix 2N2469 transistors with a BV_{ceo} (breakdown voltage, cathode-to-emitter, with base open) of 200 volts are used in the first three stages. It should be noted that transistorized amplifiers with high voltage gains are not easily designed, because semiconductors are inherently current gain rather than voltage gain devices.

Transformer T2302 steps up the input sine wave and splits its phase for purposes of full wave rectification. The input section of V2303, a dual-triode pentode 6U8, amplifies the shaped waveform to well over 150 volts peak to peak with the cathode RC network ensuring adequate gain at high frequencies. The output section of the 6U8 is a cathode follower impedance buffer from which the output waveform is coupled to the focus electrode of the CRT through a 0.05-microfarad, 5-kilovolt capacitor. A 39-kilohm resistor provides the ac load for the modulating signal, which effectively compensates for normal focal variations with deflection angle.

Since high voltage coupling transformers are a possible source of waveform distortion, the avoidance of their use in the modulator not only eliminates this difficulty but results in a modulator package of somewhat smaller size and lighter weight.

Adjustments and Test Points

When the deflection and logic assembly is installed in the recorder, the assembly's front panel is horizontal and is conveniently located at the top of the machine (see Fig. 2-1). Fig. 2-17 is a closeup photograph showing the front panel adjustments, test points, and film advance pushbutton.

Five screwdriver-type adjustments are provided: (1) focus modulation, (2) step align, (3) width centering, (4) width, and (5) step gain. The FOCUS MOD control (R-2366 of schematic J-9134-4003)

for the deflection and logic assembly is used as a fine-focus adjustment to set the level of the 400-cps paraboloidal wave modulation on the 4-kvdc for the focusing electrode of the CRT, and is adjustable over a range of 125 to 160 peak volts.

The STEP ALIGN and WIDTH CTR adjustments are used to center the trace horizontally and vertically, respectively, on the CRT face. These potentiometers are R2339 and R2336, respectively, on the referenced schematic.

The WIDTH and STEP GAIN adjustments (R2322 and R2328) are used for setting the height and width of the trace pattern, respectively.

The several test points are used in checking the various voltages required for proper operation of the assembly. With the exception of the test points for WIDTH SIG and FOCUS MOD, the proper voltages are indicated adjacent to each test point. The voltage measured at the WIDTH SIG test point will vary with the setting of the WIDTH adjustment, and is primarily of importance in determining the microseconds per inch for the trace pattern appearing on the capstan or film. The voltage read at the FOCUS MOD test point will depend upon the setting of the FOCUS MOD control and, as indicated above, will vary from 125 to 160 peak vdc.

An equalization adjustment (L2301 on the schematic) is provided on the chassis of the deflection and logic assembly for the purpose of setting the phase of the dynamic focus modulation with respect to the 8-kilocycle deflection waveform from the scan generator. When properly set, this adjustment ensures that each cusp of the paraboloidal-wave pattern occurs at the precise leading edge of the square-wave deflection waveform.

The FILM ADV pushbutton actuates a momentary contact switch controlling the main drive motor and the two film-loop drive motors. When the button is depressed, film is transported through the system until the button is released.

2.3.2 Step Scan Assembly

The step scan assembly is a small unit that is bracket mounted on the right side of the recorder (see Figs. 2-1a and 2-2). The step scan circuits, which consist of (1) a driver and (2) transistor switches whose operation is similar to that of the triangular scan generator circuits, generate a current square wave which, when applied to the step windings on the CRT yoke, causes the beam to be deflected laterally at the completion of each vertical scan. An important objective in the design of the sweep circuits was to minimize the turn-around time required for this deflection.

The input to the step scan assembly, like that to the triangular scan generator, is an 8-kilocycle square wave from the emitter follower of the scan generator assembly. The step scan circuits produce a nominal 3/8-inch movement of the beam during each turn-around interval of approximately 6 microseconds at the end of each upward and downward sweep.

The step deflection current waveform is developed by two 2N1046 transistors and a 0.1-millihenry, 0.2-ohm winding on the CRT yoke. A 75-ohm, noninductive power resistor limits the current in this coil to the approximate value required for the CRT trace. A variable resistance from the −60-volt bus is adjusted until the required current is obtained in the step deflection coil.

2.3.3 High Voltage Power Supply (HVPS)

The DDM4KV1 high voltage power supply (see Figs. 2-2 and 2-18) for the recorder was developed by Kaiser Electronics, Inc., under subcontract to Itek. Fig. 2-19 is a block diagram of this assembly; the assembly is enclosed in a sealed case 5 by 7 by 7 inches and weighs approximately 16 pounds. This supply, energized by the 28-vdc buffer supply of the aircraft, delivers to the CRT a 15-kilovolt ultor voltage, a nominal 4-kilovolt focus voltage that can be varied over an approximate range of ±7 percent, and a 500-volt first anode voltage.

To minimize degradations in trace resolution as a result of any ripple on the dc from the HVPS, the relaxation oscillator of the supply is locked in phase with the blanking pulse flip-flop of the deflection and logic assembly. This synchronization is accomplished by a phase detector that locks the power supply's oscillator in step with the blanking pulse input by comparing the phase of the oscillator's output with that of the 3.92-kilocycle driving signal from the deflection and logic assembly. The phase detector output is then a dc voltage which drives a series regulator that controls the input dc to raise or lower the oscillator frequency by the amount required to effect the desired lock. Locking occurs when the phase detector output goes to zero.

The output of the relaxation oscillator is used to drive current amplifiers whose output energizes (1) the primary of a special stepdown transformer having 15-kilovolt, primary-to-secondary insulation and four 6.3-volt filament windings for the five type 7235 high voltage regulator tubes used in the power supply, and (2) the primary of the high voltage transformer. The 10-kvdc output of the voltage-doubler circuit is (1) filtered and regulated to obtain 4 kvdc for the focusing electrode of the CRT, and (2) applied to a voltage quadrupling circuit whose filtered output provides 15 kvdc for the ultor of the CRT. The two outputs are electronically regulated for a voltage stability of ±0.01 percent after a 30-minute warmup period. To achieve the required CRT resolution and freedom from defocusing, it is also necessary that any change in the ultor voltage be reflected by an instantaneous and proportional change in the focus voltage. This "tracking" function is accomplished by sampling a portion of the 15-kilovolt ultor voltage through a tap on the 300-megohm precision voltage-ratio divider connected across the 15-kilovolt output. Since any change in ultor voltage will be accompanied by a proportional change in the sample, the latter can be used to initiate, through the 4-kilovolt electronic regulator, the proper increase or decrease in focus voltage.

The 300-megohm voltage divider across the 15-kilovolt output generates two voltages: (1) feedback to the 15-kilovolt electronic regulator, and (2) a tracking voltage. The 60-megohm voltage divider across the 4-kilovolt output generates a feedback voltage for the 4-kilovolt electronic regulator. Control of the focus voltage is effected by means of a potentiometer in the time delay assembly. This voltage is applied to the 4-kilovolt electronic regulator through the 60-megohm divider.

The 500-volt, first-anode potential is obtained from a GV3S-500 voltage regulator tube that is energized by the 4-kilovolt supply. To protect the G1 anode and gun section against transients exceeding 585 volts, a series of NE-3 neon lamps is connected across the 500-volt output.

Circuit details of the Kaiser DDM4KV1 supply are found in Itek drawing 9134-4006; this drawing is one of the electronic system schematics supplied to the customer with the recorder manual.

Connections to the HVPS are through high voltage, high altitude type connectors manufactured by Amp., Inc. Silicone grease is inserted into the ceramic connector cups for the purpose of reducing corona under high altitude conditions. The entire HVPS package, exclusive of connectors, is sealed in a silicone bath. After residual air and moisture bubbles are evacuated through the "frequency adjust" access hole in the top of the case, sulphur hexafluoride is added. By compressing this gas under the pressure produced by thermal expansion of the oil as the ambient temperature increases, case rupture is prevented.

2.3.4 Focus Modulation Coupling Assembly

The focus modulation coupling assembly comprises (see Fig. 2-2) a 0.05-microfarad, 5-kilovolt capacitor and a 39-kilohm carbon resistor. The purpose of this unit is to couple the 150-volt peak-to-peak output of the dynamic focus modulator to the focusing anode of the CRT, while isolating the 4-kilovolt potential on this electrode from the low voltage circuits of the modulator. The input connection to the coupling unit is from a cathode follower circuit at the output of the modulator; the output from the coupler goes directly to the focusing anode of the CRT.

2.3.5 High Voltage Time Delay

The high voltage time delay assembly is a small package located (see Fig. 2-2) adjacent to the high voltage power supply. This assembly contains the resistors and time delay relays used to bring the ultor and focus control voltages to rated values in three discrete steps. Also in this assembly is a 10-turn potentiometer for focus voltage control.

The high voltage time delay assembly is activated by relay S1 when the system's 28 vdc is applied to the recorder 60 seconds after the initiation of STANDBY. At this time, the primary voltage for the high voltage transformer is applied through three series resistors: 100, 20, and 5 ohms. At this reduced voltage, the ultor receives approximately 10 kvdc and the focus electrode approximately 2 kvdc.

Ten seconds after relay S1 closes, the 100-ohm resistor is cut out by closure of relay S2. The voltage on the ultor and focus electrode increase to 15 kvdc and 4 kvdc, respectively. Five seconds later, relay S3 closes to short out the 20-ohm resistor, which damps the reverse current switching transient.

At rated input voltage, the focus voltage can be varied from 4,300 to 3,850 volts. At any setting of the focus voltage potentiometer, the voltage on the focus electrode will be known with an accuracy of ±1/4 volt.

2.3.6 Automatic Brightness Control (ABC) Assembly

The automatic brightness control assembly is mounted on the right sideplate of the recorder (see Figs. 2-1a and 2-2). The primary purpose of the ABC circuits is to sense the intensity of the CRT trace, and to develop a signal that can be used to maintain the brightness at a predetermined level during the operation of the recorder.

Fig. 2-20 is a block diagram of the ABC circuits, whose input is a 3.92-kilocycle chopped wave from an IRC-type B2M selenium photocell located within the light shield at a position above the CRT. Since the sensor is so positioned that the only illumination reaching it is that provided by scattered light from the trace at the top of the sweep pattern, masking of the information carrying portion of the trace is obviated.

As the CRT trace is swept out, the sensor output is a 3.92-kilocycle, low level sine wave (on the order of millivolts) which enters the ABC assembly through a 4-kilocycle bandpass filter and is fed to a six stage, high gain, narrow band amplifier whose center frequency is 4 kilocycles. This solid-state amplifier is a Westinghouse 2-kilocycle unit modified for 4-kilocycle operation. Its gain, on the order of 10,000, provides a saturation level output of approximately 60 volts peak to peak at an input level of 1 millivolt. This output is full-wave rectified and fed to an emitter follower delivering −2 to −30 vdc, depending upon the sensed brightness level. This negative feedback voltage is fed (1) to the control grid of the CRT through the ON/OFF switch of the bias control assembly which permits the automatic feature to be disabled for purposes of calibration and testing, and (2) a remote brightness indicator that utilizes a Schmidt trigger. If the trace disappears due to a malfunction, the trigger closes the relay of a circuit used to light a malfunction warning lamp.

The operating level to which the trace brightness is maintained by the ABC circuit is established by the setting of a brightness control on the bias control assembly.

2.3.7 Bias Control Assembly

The bias control assembly is a small unit mounted (see Fig. 2-1 and Fig. 2-2) at one end of the recorder and external to it. Fig. 2-21 is a closeup photograph of the assembly showing the controls and test points.

The OFF/ON switch for ABC INTENSITY is used to switch in, or to disable, the ABC feature. The INTENSITY control is used to set the illumination level to which the ABC circuitry automatically controls the CRT when the OFF/ON switch is in the ON position, and to control the nominal light level when the switch is in the OFF position.

The VAR FREQ/FIXD FREQ switch is used to select either a fixed film speed, determined by the output of a 400-cps tuning fork oscillator, or to permit the film transport velocity to be automatically controlled by a signal input (from the aircraft navigation system) which varies the film velocity as a function of sensed ground speed.

The fine frequency ADJ control is used primarily during the initial setup of the recorder. After the potentiometer for the RN (ground speed) input to the speed controller assembly is adjusted for the specified dial reading, the fine frequency control is used to bring the frequency of the film drive voltage to exactly 400 cps.

The several test points on the panel of the bias control assembly provide the means for measuring or monitoring (1) the fixed (400 cps) or the variable (350 to 450 cps) output of the speed controller, (2) the ac and the dc calibration of the brightness control circuits, and (3) the −150 vdc for the speed control assembly.

2.3.8 Data Flash Assembly

The data flash assembly, located (see Fig. 2-1a) on the right sideplate of the recorder, consists of a unijunction RC pulse generator, a solid-state switching device, pulse generator, and relay driver. The oscillator establishes the basic timing rate for firing simultaneously the two data flash tubes in the data projector assembly. With the film moving through the recorder at a nominal rate of 2 inches per second, and the flash tubes firing every 10 seconds, the reduced size image of the 24-hour clock and the alphanumeric characters on the data card in the data projector appear at 20-inch intervals along the edge of the film.

Fig. 2-22 is a schematic of the data flash circuits. Each cycle of the unijunction transistor generator, Q2314, causes the stored charge on each of two 0.22-microfarad capacitors to energize, through a silicon PNPN switch, Q2327, the primary of an associated high voltage transformer whose output triggers its associated flash lamp into conduction. As the two flash lamps simultaneously ionize, the charge on an 86-microfarad capacitor is dumped through both lamps to produce a light flash of very high intensity and extremely short duration. This capacitor, and the two transformers, although functionally a part of the data flash system, are not located in the data flash assembly. The transformers are enclosed in a small rectangular package adjacent to the data block portion of the data projector; the capacitor is mounted on the inner surface of the recorder's left sideplate.

In addition to controlling the data flash rate, the unijunction pulser energizes a silicon NPN transistor, Q2326, that energizes an external 28-volt relay, K2303, six times per minute in synchronism with the flash pulse.

2.3.9 Speed Control Assembly

The speed control assembly (see Fig. 2-2) is a package 8 inches long, $4\frac{3}{4}$ inches wide, and 4 inches high that weighs approximately $4\frac{1}{4}$ pounds. The purpose of the speed control circuits is to provide for the precise control of film velocity in one or the other of two operating modes: (1) at a fixed rate of 2 inches per second (corresponding to a particular aircraft ground speed), or (2) at a rate proportional to any ground speed within ±10 percent of the particular ground speed.

Fig. 2-23 is a block diagram of the speed control circuits. As is seen, a voltage regulator in the speed control assembly provides approximately 120 vdc for the remotely located navigation

potentiometer (RN) whose instantaneous setting and the voltage resulting therefrom are a function of the aircraft's ground speed. The ground speed voltage is applied to a variable frequency, voltage controlled oscillator through a low speed cutoff (in the frequency controller) which passes voltages in excess of 25 volts. The oscillator output frequency is thus directly proportional to ground speed. This output is limited to a maximum frequency of 450 cps by a Schmidt trigger (also in the frequency controller) which effectively clamps the oscillator control voltage at approximately 32 volts.

The 25 to 32 vdc from the frequency controller is applied to the variable frequency, voltage controlled oscillator whose output frequency is, at any time, a function of the aircraft's ground speed.

Film drive at a precisely controlled rate of 2 inches per second is made possible by the 400-cps tuning fork oscillator of the speed control assembly. The fixed and variable speed outputs are fed to the VAR FREQ/FIXD FREQ switch on the bias control assembly. The selected oscillator then energizes a driver unit for the power amplifier. Power amplifier output is a nominal 115 vac for either operating mode.

The fine frequency ADJ control of the bias control assembly is used in adjusting the output of the voltage regulator to the proper level for achieving a 400-cps output from the variable frequency oscillator at a specified setting of the remotely located RN navigation potentiometer.

Fig. 2-24 is a schematic of the speed control (inverter) system. The input regulator requires a +150-vdc source, preferably regulated; the nominal output to RN is 120 vdc. The Darlington emitter follower buffer couples the voltage from the wiper of RN to the Royer voltage controlled oscillator (VCO) circuit. The square-wave output of the VCO drives a two-transistor power output stage that, in turn, energizes the synchronous motor. Thus a change in setting of RN results in a linear and direct change in motor and film speed. A switch at the input of the power stage allows the motor to be controlled by RN, or driven at a constant rate by the 400-cps tuning fork oscillator.

Q16 provides the gain needed for the tuning fork oscillator. Q17 is an emitter follower buffer which feeds amplifier Q18. Driver Q13 operates at the variable rate or fixed rate depending on the position of the mode selector switch.

The regulator, designed to operate over a temperature range of −55 °C to + 85 °C, provides an output voltage of 110 to 130 volts. The navigation potentiometer, RN, as well as the Darlington-connected emitter followers (Q16 and Q7), are connected across the 120-volt (nominal level) bus. These transistors are selected for their high voltage capabilities. The voltage at the emitter of Q7 is passed through the contacts of relay K and thence to the oscillator circuit. A proportional voltage is sensed across potentiometer R10 by the Schmidt trigger circuit. The trigger is so adjusted that a voltage above 36 volts switches a 36-volt zener diode, D5, across the input to the oscillator to prevent burnout of Q10 and Q11 (which "see" twice the input voltage to the oscillator). The voltage at the emitter of Q7 can rise as high as 120 volts if RN swings to its high end. Since relay K does not operate below 450 cps (as a minimum), and if a fairly even vehicle speed is maintained, relay K may not be energized at all during a flight. Emitter follower Q12 couples the square wave from the VCO into power stage driver Q13. The switching transistors, Q14 and Q15, for the power amplifier are a pair of 2N1099's which, having a low thermal resistance, provide good reliability under conditions of high ambient temperatures.

With the exception of the power amplifiers, which are germanium PNP types, the transistors of the speed control assembly are silicon NPN semiconductors. The germanium PNP type is a more efficient power switch because of its lower saturation voltage.

Fig. 2-25 shows a plot of output frequency versus RN setting over the specified operating range of 350 to 450 cps.

Fig. 2-26 shows the absence of slope error due to the oscillator transformer equation. The plot shows that the frequency is zero when the voltage is zero (RN at zero), as the equation shows it must.

2.3.10 Loop Control Assembly

The loop control assembly consists of two microswitches mounted on the inside of the right side plate, a pair of speed adjust potentiometers bracket mounted on the outside, and the Globe dc motors (see Fig. 2-2). The purpose of the loop control system is to maintain the freestanding supply and takeup loops at a predetermined length. Each loop is controlled by the pressure of the film loop at a point where it contacts the finger of an actuating arm on a microswitch.

Whenever either film loop exceeds the predetermined length, an associated microswitch closes a circuit that connects a resistor in series with the associated speed-adjust potentiometer and the field coil of the 28-vdc drive motor for that loop. This action slows the motor until the loop is restored to normal size and the microswitch opens to cut out the resistor. As a result of this control, each loop slowly oscillates from a maximum to a minimum position over a small range established by the hysteresis (dead band) of the microswitch. By minimizing film tension in the region of the exposing slit at the capstan roller, the loop control system eliminates those photographic degradations that would otherwise be introduced by film transmitted vibrations originating in the recorder or the aircraft.

2.3.11 Cathode-Ray Tube

The CRT (see Fig. 2-27) used in the recorder is the WX4903P11, a tube developed by the Westinghouse Electric Corporation of Elmira, New York. This tube, designed for a 0.5-mil spot size, is a tetrode type employing a bipotential, electrostatic focus lens.

To meet the stringent operational requirements established for this tube, it was necessary to develop a microtriode structure (for the electron gun) which basically consists of two cone-shaped elements spaced by an alumina ceramic ring; the entire assembly is brazed in a hydrogen atmosphere. The G1 and G2 cylinders are machined from molybdenum stock. To provide a good expansion match between the molybdenum and the ceramic, and to prevent breakage or shifting of the elements during tube fabrication, a 96 percent alumina ceramic was chosen.

The focus lens is formed by the focus bell and the sidewall of the tube. This bipotential-type electron lens can handle larger diameter beam bundles with less distortion than any of the more conventional electrostatic lenses.

The cathode of this CRT is a triple carbonate oxide type. Despite certain limitations, this cathode is capable of producing the loading required when operated at approximately 80 percent efficiency and approximately 75 degrees above its normal operating temperature.

The G1 cylinder, G3 cylinder, and mounting ring are assembled on a solid mandrel by glass beading. The retainer ring is welded into the G1 cylinder, and the microtriode structure—with the appropriate cathode spacer, cathode, and retainer—is inserted into the G1 cylinder. The focus barrel, focus cup, mica spacers, and masking apertures are welded in place after assembly to the G3 cylinder.

The phosphor screen is of the evaporated, transparent type in which the P11 phosphor is deposited by a cataphoretic (electrochemical plating) technique. The cataphoretically coated screen is capable of providing a brightness that is only slightly less than that from a settled screen, does not limit resolution in the recorder application, and can be satisfactorily reproduced.

To obtain a high quality tube face with a face flatness not achievable in conventional glass molding operations, a separate faceplate is sealed to the funnel neck assembly by a frit glass

sealing technique. Fig. 2-28 is an outline drawing showing the tube shape and dimensions. Table 2-2 summarizes the principal characteristics of the WX4903P11, and Fig. 2-29 is a plot showing the transfer characteristics of experimental tube 207.

The yoke of the CRT, in addition to the two conventional coils for centering and two coils for line scan, has a single coil for introducing step deflection of the beam at the extremes of the vertical scan. The five coils form an integral unit. The centering coils are part of two bridge circuits which permit current flow in both the forward and reverse direction for right/left and up/down sweep centering adjustments.

2.3.12 Video Amplifier

The video amplifier is a customer supplied item that is mounted (see Fig. 2-2) on the same end of the recorder as the bias control assembly. The amplifier package is 14 inches long, 5½ inches wide, and 3 inches deep. It weighs approximately 3 pounds and has a nominal passband of 40 megacycles. The input to this unit is the video signal output of the aircraft's pulse radar. Video amplifier output goes to the control grid of the recorder's CRT.

2.4 REMOTE CONTROL SYSTEM

After the recorder has been installed in the aircraft, checked out, and loaded with film, its operation is remotely controlled by means of a master selector switch on the AN/APQ-93 control panel. This switch has the following positions: (1) OFF, (2) STANDBY, and (3) TRANSMIT.

When the selector switch is in the OFF position, the recorder is completely deenergized.

When the switch is set to STANDBY, the following events occur:

1. Heater current is furnished to the relatively few tubes in the recorder by supplying a special +28-vdc (not the system 28 vdc applied later) and 115-volt, 400-cps power to the appropriate assemblies in it; the 6.3-vac heater voltage for the customer supplied video amplifier is supplied directly to the amplifier from the Westinghouse power supply.

2. Sixty seconds after STANDBY is initiated, closure of a relay in the Westinghouse supply causes the remaining externally supplied voltages (system 28 vdc, +300 vdc, +150 vdc, −150 vdc, +60 vdc, and −60 vdc), and the 4-, 8-, and 16-kilocycle pulses, to be applied to the recorder. The recorder electronics are then fully energized, but the ultor voltage is held to approximately 10 kilovolts and the focus voltage to approximately 2 kilovolts for 15 seconds.

3. Approximately 15 seconds after the recorder electronics are energized, the dropping resistor is shorted out to provide rated ultor and focus voltages.

When the selector switch is set to TRANSMIT, a 28-vdc signal closes the main film drive relay (see Fig. 2-30, a schematic of the recorder's internal control system) to energize the film transport system, and the radar video is supplied to the recorder.

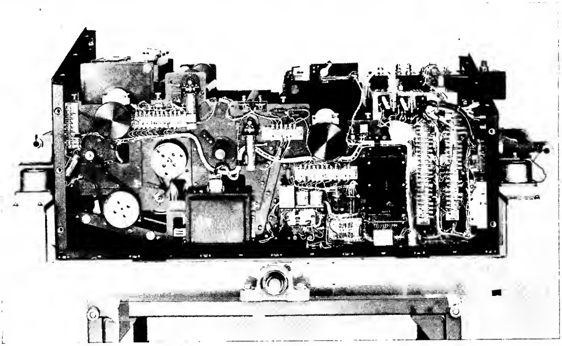
Table 2-1 — Recorder Component Weights

Component	Weight, lbs	Cumulative Total
Structural		
Frame	41.8	
Covers	21.0	
	62.8	62.8
Optical		
M1/M2 mirror and prism assembly	9.0	
Lens and M3 mirror assembly	23.0	
Data projector	2.2	
	34.2	97.0
Film Transport System		
Supply cassette assembly	4.0	
Storage cassette assembly	3.5	
Capstan drive assembly	4.2	
Supply loop drive assembly	2.7	
Takeup loop drive assembly	2.0	
Torque motor assembly (2)	3.2	
Pulley assemblies and motor	4.12	
Drag roller and film motion detector	3.5	
Speed control assembly	4.25	
Loop control assembly	0.38	
Bias and speed control assembly	0.63	
	32.48	129.48
Electronics		
Cathode-ray tube assembly	14.0	
Deflection and logic assembly	6.63	
Step scan assembly	1.19	
High voltage power supply	16.0	
High voltage time delay assembly	1.0	
Automatic brightness control assembly	1.38	
Data flash assembly	0.63	
Focus modulation coupling assembly	0.56	
Miscellaneous small components	7.13	
Cabling	3.0	
	51.52	Total 181 lbs

Table 2-2 — Typical Characteristics of WX4903P11 CRT

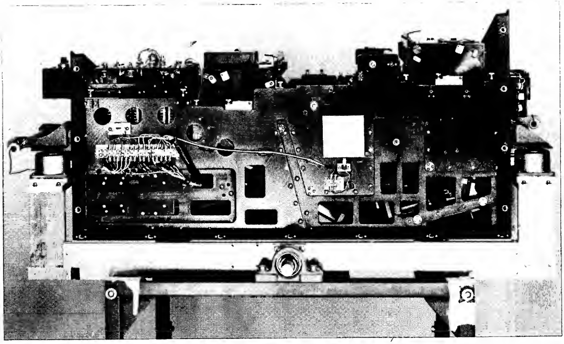
Anode voltage	15,000
G2 voltage	500
Focus voltage	4,090 (approximately)
Heater voltage	6.3 at 450 milliamperes
Spot cutoff voltage	72.0 (approximately)
Line width*	
At 1 microampere	0.63 mils
At 2 microamperes	0.66 mils

* Measured at half-amplitude point of curve plotted from data obtained with slit-line-scan techniques for measuring light energy distribution of the line.



6117

(a) Right-side view



6118

(b) Left-side view

Fig. 2-1 — Recorder

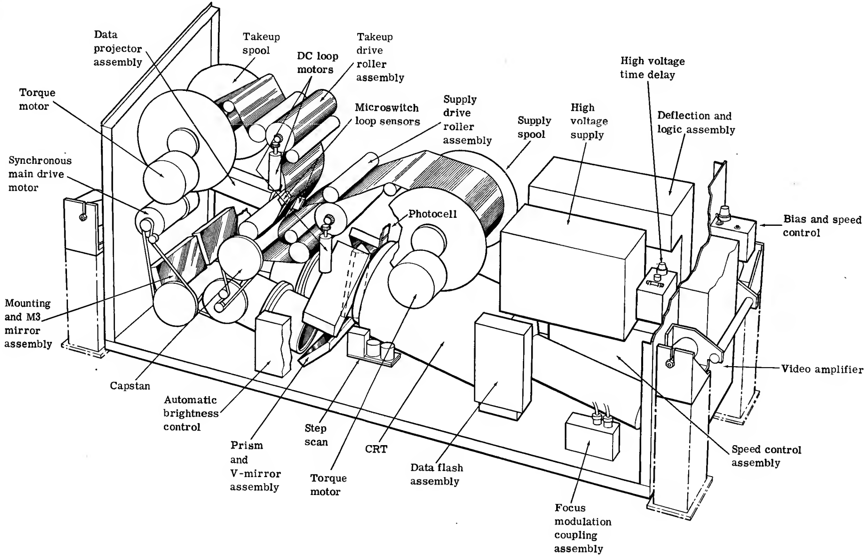


Fig. 2-2 — Locations of principal assemblies and components (cutaway perspective drawing)

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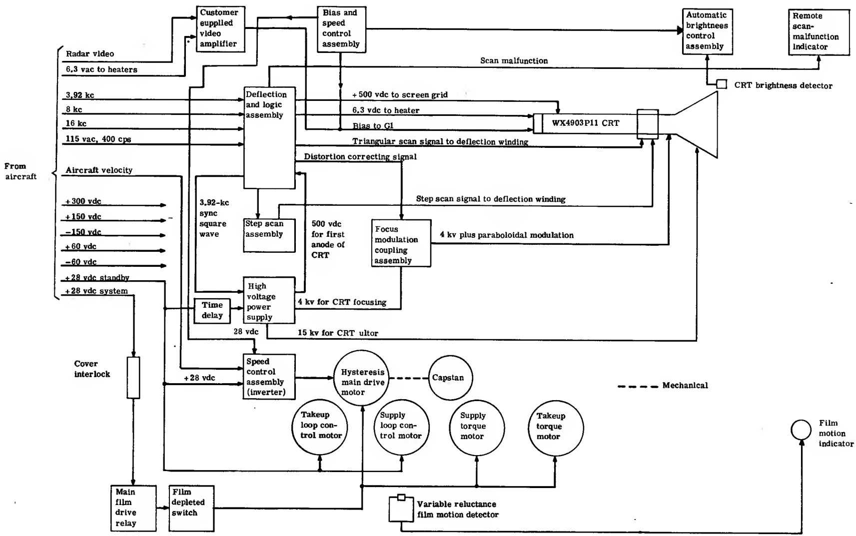

Fig. 2-3 — Functional block diagram of recorder

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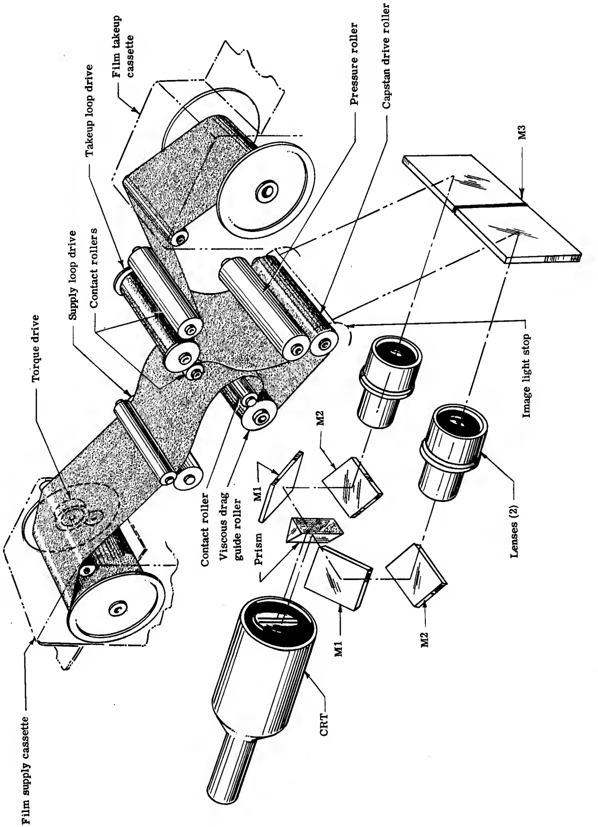

Fig. 2-4 — Pictorial schematic of recorder film transport and optical system

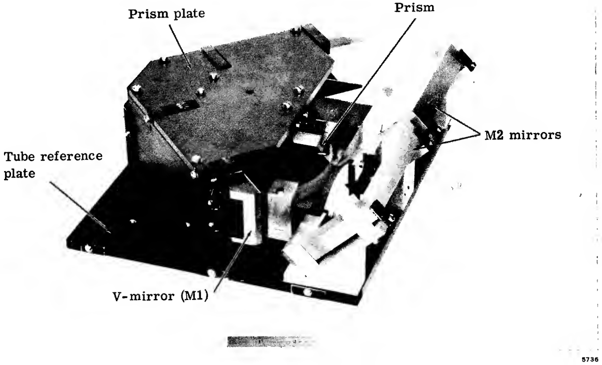

Fig. 2-5 — Prism, V-mirror, and M2 mirror assembly

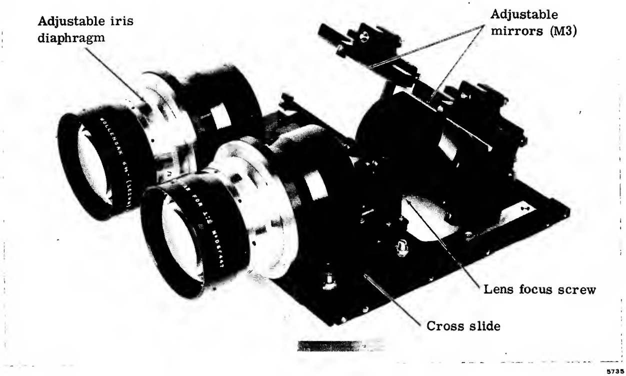

Fig. 2-6 — Lens and M3 mirror assembly

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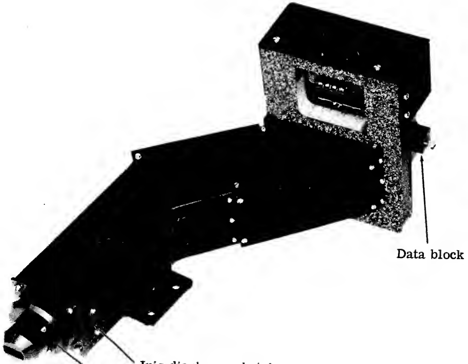


Fig. 2-7 — Data projector assembly

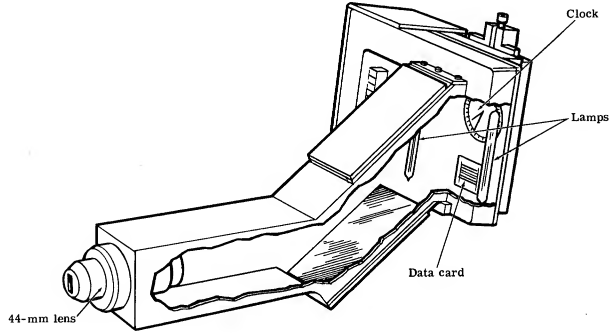
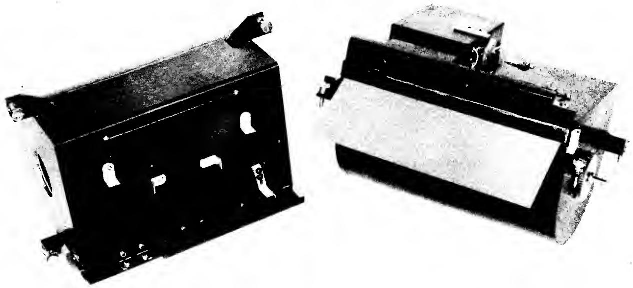


Fig. 2-8 — Cutaway drawing of data projector assembly

Fig. 2-9 — Trace viewing assembly



Film storage cassette

Film supply cassette

5817

Fig. 2-10 — Film cassettes of High Resolution Radar Data Recorder

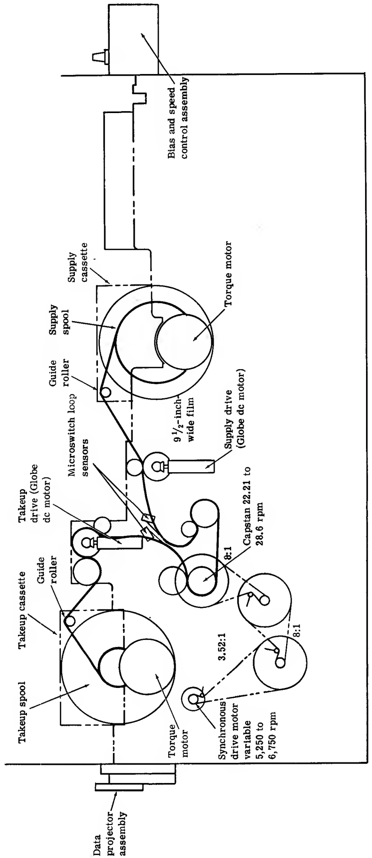
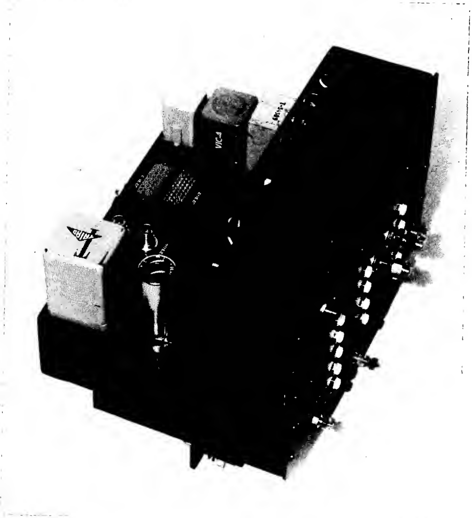


Fig. 2-11 — Drawing showing film path through recorder



5820

Fig. 2-12 — External view of deflection and logic assembly

1. NAME OF RECEIVING CO. | 2. ADDRESS | | | 5. OUT-GOING LOG NO.

Commanding
Advanced Plans &
Programs Div. (ASZ-5)

Wright-Patterson
Air Force Base, Ohio

9/2/66

HC

86-E-74359-66

6. DESCRIPTION:

Deputy for Systems Management
Hq. Aeronautical Systems Div.

86-20779 # 26

86-24336 #6

86-34832 # 1

86-34833 # 1

86-34834 # 1

86-34835 # 1

86-34836 # 1

86-34837 # 1

Attn: Mr. L. Karably

Handcarried by Roy C. Fox

I ACKNOWLEDGE RECEIPT OF THE ABOVE DOCUMENTS.

7. NAME OF RECEIVER (PRINT): L.S. Karably

8. SIGNATURE OF RECEIVER: L.S. Karably

9. DATE REC'D.: 2 Sept. 66

PLEASE SIGN, DATE AND RETURN REPLY CARD TO WESTINGHOUSE.

EXTERNAL DOCUMENT RECEIPT AND REGISTER

(FORM BA 5012F)

Approved For Release 2009/07/08 : CIA-RDP67B00657R000100140001-4

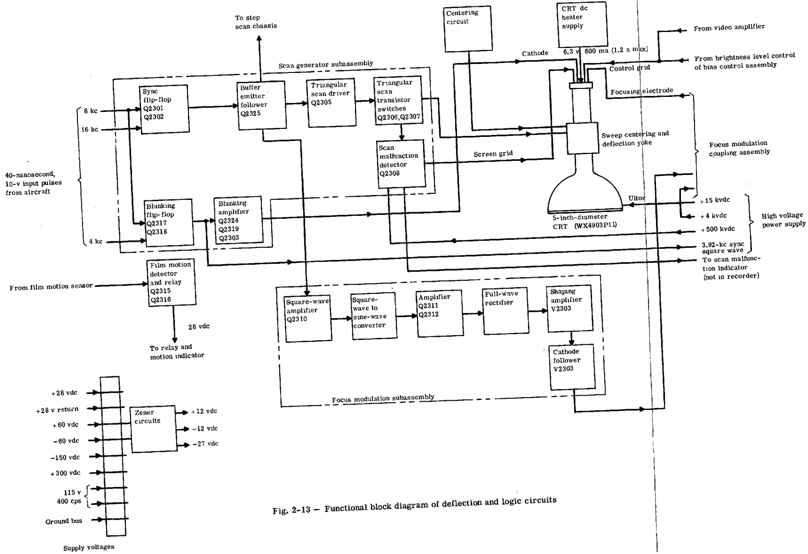


Fig. 2-13 — Functional block diagram of deflection and logic circuits

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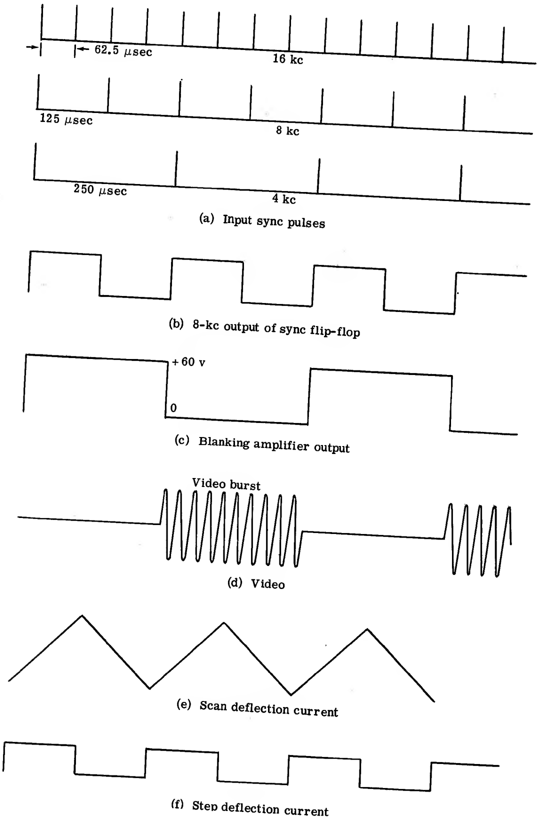

Fig. 2-14 — Recorder waveform relationships

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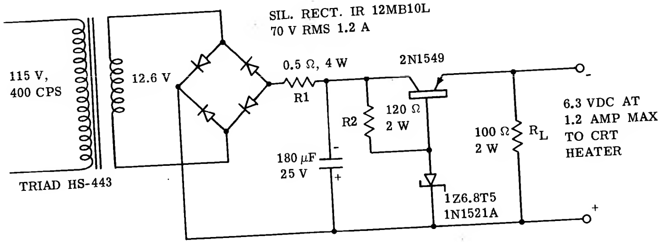
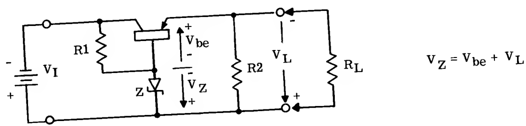


(a) Schematic



(b) Equivalent circuit

Fig. 2-15 — CRT dc heater supply

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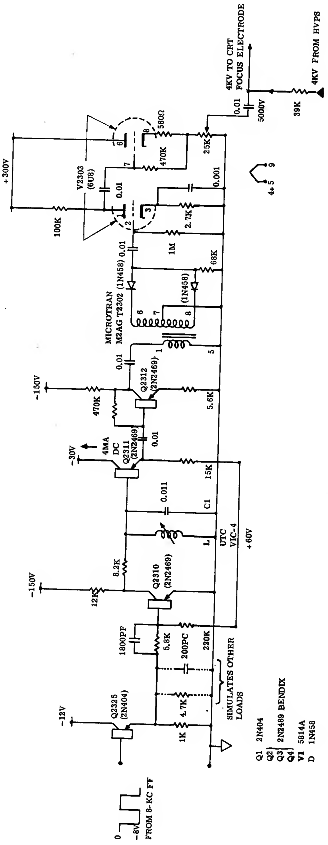

Fig. 2-16 — Schematic of dynamic focus modulator

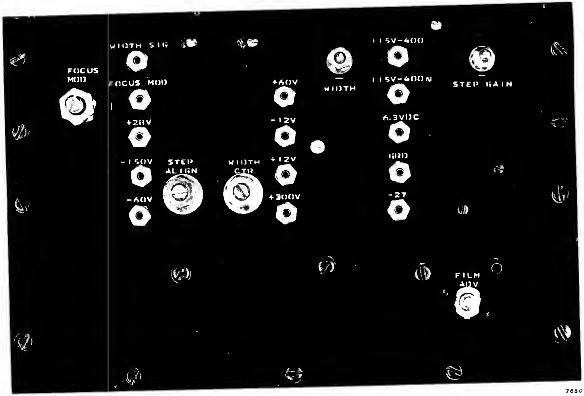

Fig. 2-17 — Front panel of deflection and logic assembly

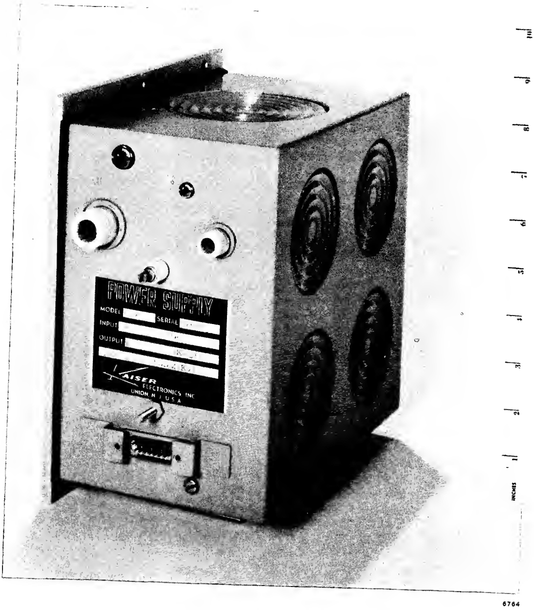

Fig. 2-18 — Kaiser high voltage power supply

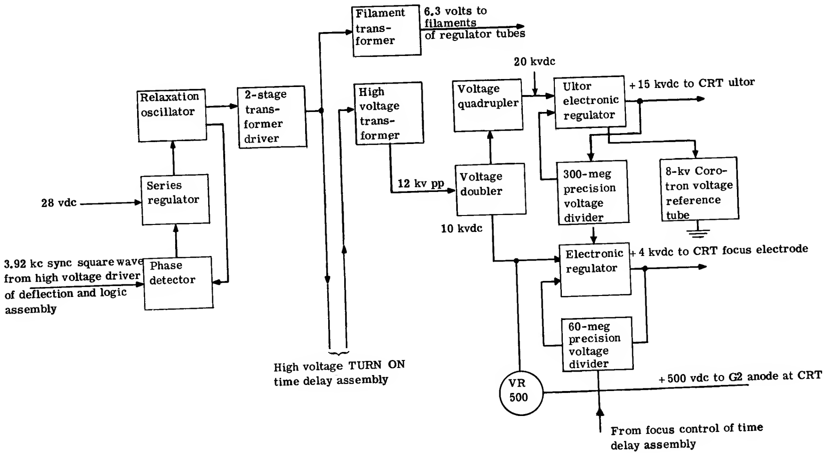

Fig. 2-19 — Block diagram of high voltage power supply

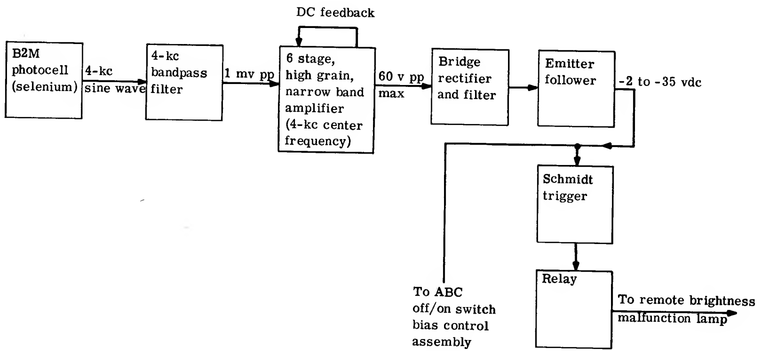

Fig. 2-20 — Block diagram of CRT automatic brightness control circuit

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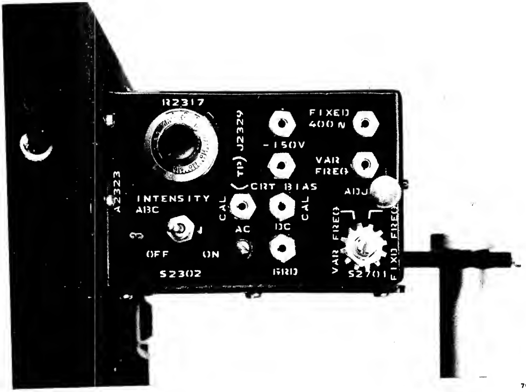

7679

Fig. 2-21 — Bias control assembly

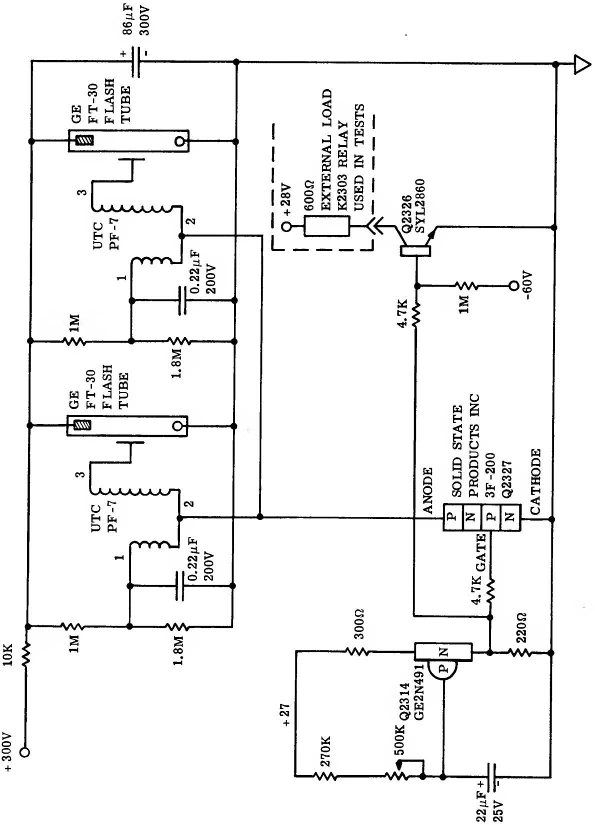

Fig. 2-22 — Schematic of data flash circuit

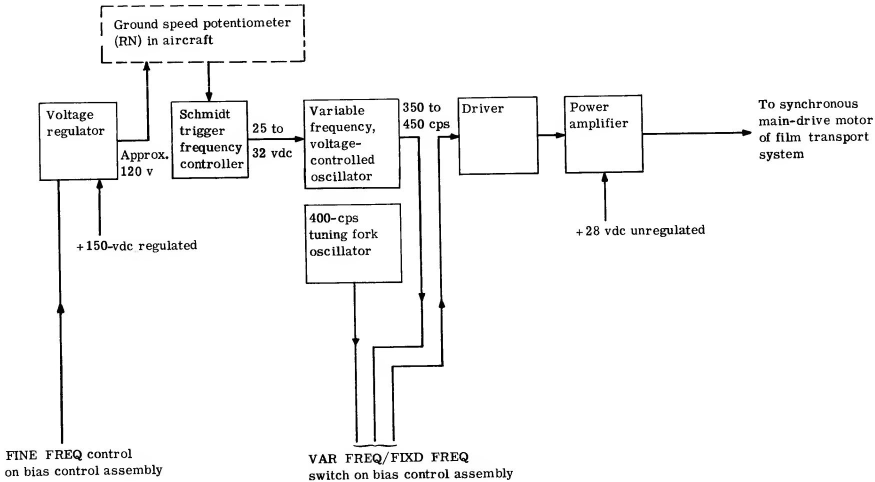

Fig. 2-23 — Block diagram of speed control circuit

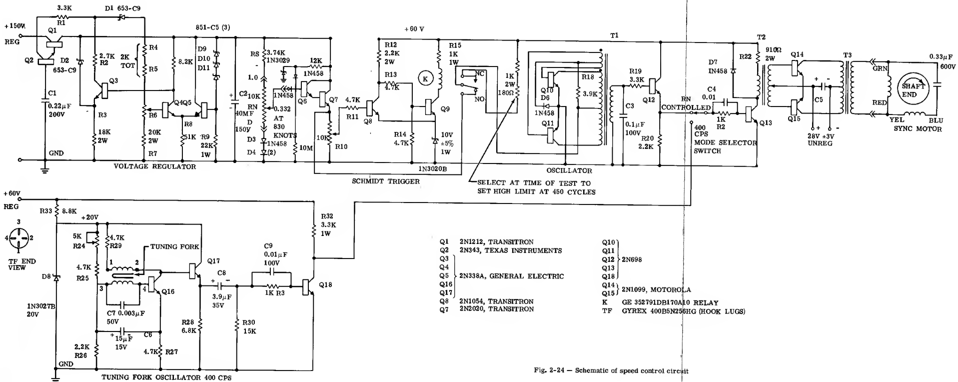

Fig. 2-24 — Schematic of speed control circuit

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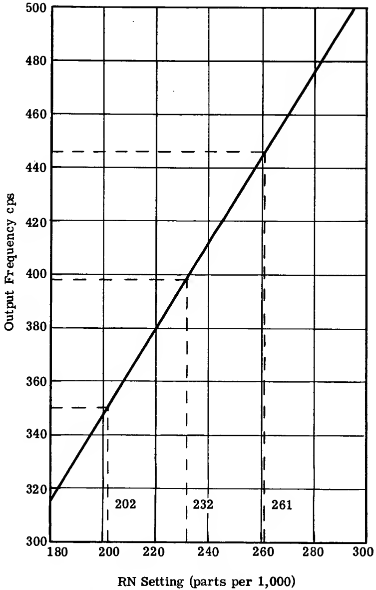

Fig. 2-25 — Speed of control output frequency as a function of RN setting

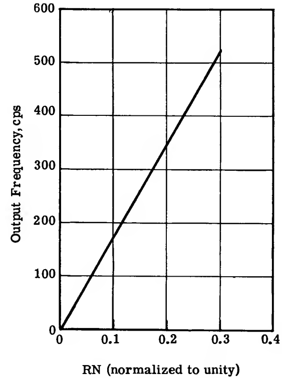

Fig. 2-26 — Normalized plot of speed control output frequency versus RN setting, showing absence of slope error

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Fig. 2-27 — Westinghouse WX4903 CRT

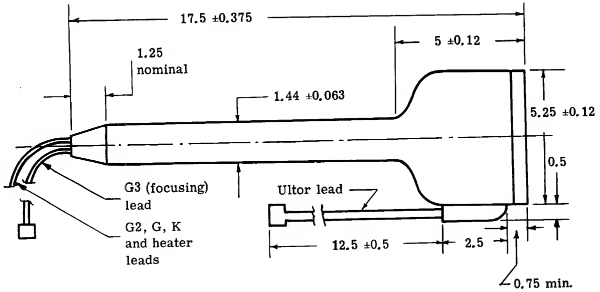

Fig. 2-28 — Outline drawing of WX4903 CRT

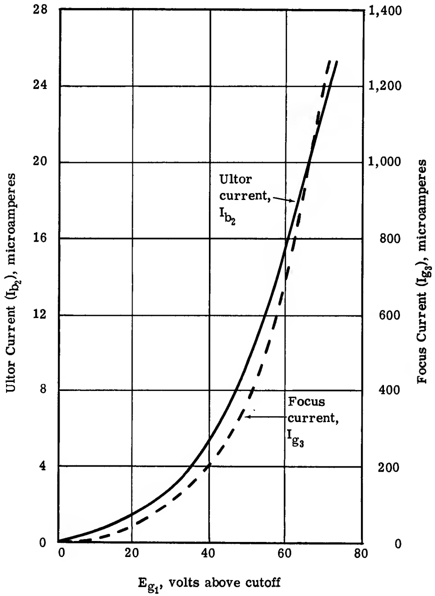

Fig. 2-29 — Typical transfer characteristics of WX4903 CRT

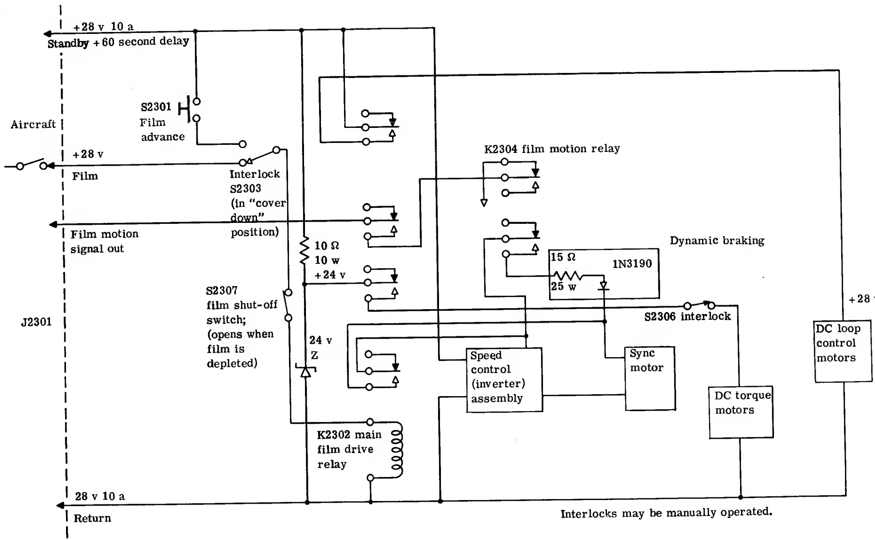

Fig. 2-30 — Schematic of recorder internal control system

3. RECORDER DESIGN

The severe space and weight limitations placed on the recorder, together with performance requirements which actually exceeded state-of-the-art capabilities, necessitated a carefully planned approach that enabled tradeoffs among the optical, mechanical, and electronic design parameters. The more significant problems encountered in the design and development are discussed below, under appropriate headings. Performance data are given in Section 4.

3.1 OPTICAL SYSTEM

In considering a basic optical design for the radar data recorder, it was apparent at the outset that the most desirable method for transferring the CRT trace to the film was—in terms of weight, space, and uniformity of resolution over the full width of the trace—a fiber optics approach. However, it was also recognized that the state-of-the-art capabilities in this relatively new technique might well pose insuperable difficulties at the desired resolution of 80 lines per millimeter.

After weighing these and other factors, it was decided that the initial design should be predicated upon the fiber optics approach. As will be seen in the following discussion of the fiber optics development, the attainment of a satisfactory fiber optics unfolding array proved impossible in the time scale established for the program, and recourse to a dual-channel standard optical system, with folding mirrors that would provide the packaging density necessitated by the limitations on recorder overall length, was accepted as the only feasible alternative.

Since the decision to abandon the fiber optics approach was reached only after exhaustive efforts to overcome the problems encountered during unfolding array fabrication, the mechanical design and layout of the first three recorders was predicated on the short term availability of a satisfactory fiber unfolding array and a CRT having a spot size of 1/2 mil or less. Inasmuch as these hopes were not fully realized, each of these recorders was conditionally accepted.

3.1.1 Fiber Optics

The development of the fiber bundle for this unfolding array proved extremely troublesome. Mosaic Fabrications, Inc., of Southbridge, Massachusetts, undertook its initial fabrication, using fibers of 5-micron diameter. This task required the fusing of multifiber bundles into sheets approximately 8 inches long, 4.5 inches wide, and 1/8 inch thick. After the bundles were fused, each of the two sheets had to be folded into the complex shape necessary for the required unfolding function, and then mechanically assembled into a structure suitable for the potting and polishing of the input and output ends of the fibers. The possibility of destroying the fiber assembly in any of the many fabrication stages was great, so progress was correspondingly slow. Mosaic Fabricators, Inc., eventually delivered several samples in which various sections were rendered inactive as a result of breakage during fabrication, but which still permitted evaluation of the performance in undamaged areas.

When the best of these samples was installed in the recorder and exposures were made on SO-243 film, it was discovered that the transmission factor of the array (on the order of 15 percent) was too low to deliver sufficient illumination to the film. A change to a film with greater speed (but poorer resolution) permitted the making of experimental exposures, but several new problems then appeared. Examination of the trace image at the output end of the fibers showed that the trace was broken up into segments, each segment being associated with one multifiber bundle. Since these bundles became twisted during construction of the array, the trace segment assumed a false orientation and the resulting trace consisted of a series of short, 0.1-inch segments, each of random orientation. Film exposed to this trace showed a striated pattern in which the modulation of the CRT was barely discernible.

These results were communicated to Mosaic Fabrications, Inc., who then attempted to correct the difficulty in subsequent arrays by making the multifiber bundles in a rectangular shape that should, in theory, have left the image orientation unchanged. However, when the rectangular bundles were fused together, they showed a tendency to fracture across the grain of the fibers during the annealing process, and a successful array of this type was never delivered.

In the meantime, a backup source for the unfolding array had been consulted. Their approach was to use fibers of 10-micron diameter, and to assemble the entire array mechanically, i.e., without the use of fusing or other heat processes. In general, this array proved somewhat more successful than the array by Mosaic Fabrications, Inc., and several units of this type were delivered to Itek. Unfortunately, the 300-cycle-per-inch resolution by the best of these units was unacceptable for the intended application.

3.1.2 Standard Optics

It was assumed in the preliminary design of the conventional-optics recorder that its outside dimensions would be the same as those of its fiber optics predecessor. This space restriction posed some extremely difficult problems in packaging a high resolution optical system capable of projecting a 9-inch-long image of the CRT trace onto the film. Numerous designs were drawn up, including one which combined eight traces. The latter required eight different lenses and eight sets of mirrors, working at 1:4 projection ratio. One system designed at that time did not differ much from the final configuration, except that between the lens and film station in each of the two optical paths, four mirrors were to be used instead of one. This complexity appeared necessary in order to increase the length of the path to a point at which the field requirements for the lens would not be prohibitive.

After agreement had been reached on increasing the length of the recorder by $5\frac{3}{4}$ inches, Westinghouse suggested a layout which offered a practical solution to the packaging problems encountered at the time. This design, which called for a pair of $6\frac{3}{8}$-inch-focal-length Wollensak special input Raptars, was the basis for the final optical system. Since this system has some drawbacks with respect to light vignetting, alignment, and mechanical interferences with the film transport system, Itek modified the design to an arrangement which facilitated alignment and reduced the number of drive changes. This modified design allowed a full $4\frac{1}{4}$-inch trace to be projected through each optical path; vignetting of the cone of light from any point was minimized at wide apertures, and became insignificant at the smaller lens apertures ultimately used. This improvement was effected by making each trace slightly asymmetrical with respect to the lens axis and accepting an unavoidable difference in resolution at the two ends of each trace.

The original optical design, aimed at achieving an axial lens-film resolution of 80 lines per millimeter (about 2,000 optical line pairs per inch), was predicated on the ultimate availability of a CRT whose spot size would be 0.0005 inch or less. Since data on spot intensity was extremely limited, and a film type had not been chosen, it was decided that the lenses would be required to

operate at full (f/2) relative aperture, i.e., an effective aperture of f/4 in the contemplated 1:1 system.

Actual recorder operating temperatures were likewise unknown, although the specification called for satisfactory performance in the range of 70°F to 140°F. In view of the substantial internal temperature increase anticipated during recorder operation, the thermal expansion of the lens and mirror mounts was expected to cause a change in path length, especially if the lenses were to operate at full aperture.

The total depth of focus (i.e., focal range) in a diffraction limited optical system is given by the expression

$$FR = 4\lambda(f/no.)^2$$

where FR = focal range in microns

λ = wavelength in microns

With an effective aperture of f/4 and $\lambda = 0.46$

$$\begin{aligned} FR &= 4 \times 0.46 \times 16 \\ &= 29 \text{ microns} \\ &\approx 0.00115 \text{ inch} \end{aligned}$$

The sine-wave limiting resolution of a "perfect" lens is found from the expression

$$R_p = \frac{1}{\lambda(f/no.)}$$

which in the above example becomes

$$R_p = \frac{1}{46 \times 10^{-3} \times (f/no.)} = 540 \text{ lines per millimeter}$$

In an optical system which neither operates nor is designed to operate at its diffraction limit, the depth-of-focus computations are subject to several uncertainties, one being that the modulation transfer function of a lens can change radically and asymmetrically from one side of best focus to the other. This effect is due to aberration, principally spherical aberration. Although several methods exist for calculating the geometrical depth of focus, none can provide a definitive answer as to what the actual performance will be. One method is simply to scale the depth of focus to the resolution required when compared with the theoretical limit. Thus, if the theoretical resolution of a lens is 540 lines per millimeter and the theoretical maximum focal range is 0.029 millimeter, the focal range for 80-lines-per-millimeter resolution is (540 ÷ 80) × 0.029 = 0.196 mm, or approximately ±0.004 inch from best focus.

A more exact method is to allow the circle of confusion to be as great as the spot size in the limiting case, and then to compare this circle with the relative aperture both inside and outside best focus. In this case

$$\begin{aligned} FR &= \pm \frac{f/no.}{\text{resolution in lines per millimeter}} \\ &= \pm 4 \div 80 = \pm 0.05 \text{ millimeter} = \pm 0.002 \text{ inch} \end{aligned}$$

These figures give a reasonable estimate of the tolerance required to hold the recorder's optical system in good focus.

In addition to considering depth of focus as a function of thermal expansion, it was also necessary to consider the change in focal length of the lenses under operational conditions. The nominal lens focal length, f, at sea level (atmospheric index of refraction, $n_D = 1.003$) was 6.375 inches. However, under operational conditions (air pressure = 4.8 psi), the index of refraction is approximately 1.0001. Actually, the effective focal length can be determined only by ray tracing and is generally not directly proportional to the index change. As a rough approximation, however, the effective focal length at altitude is found from the expression

$$f_{alt} = f_{SL}\left(n_{D_{alt}} / n_{D_{SL}}\right) = \frac{6.375}{1.002}$$

$$= 6.3737 \text{ inches}$$

Now, if the optics were set up for 1:1 magnification under normal atmospheric conditions, the total object-to-image distance, D, disregarding the separation of principal points, would be four times the focal length of the lens, i.e., D = 4f, a conclusion which follows from the fact that 1, the object distance, and 1′, the image distance, are each equal to 2f.

Then, if f equals 6.375 inches at sea level, 1 and 1′ equal 12.75 inches. Although at the operational altitude 1 remains at 12.75 inches, f becomes 6.3737 inches and L′, the new image distance, is

$$L = \frac{f \times 1}{1 - f}$$

$$= \frac{6.3737 \times 12.75}{12.75 - 6.3737}$$

$$= 12.745 \text{ inches, or an image shift of about 0.005 inch}$$

This condition places the focal plane inside the image plane associated with sea-level conditions, and beyond the limiting position originally established by the tolerance on depth of focus. Since the film is approximately 0.0054 inch thick, this situation is overcome by focusing the image on the capstan itself, rather than on the film.

After the first all-Invar recorder had been built (see Section 3.2, Mechanical Design) and several studies of its performance had been evaluated, it was evident from the failure to achieve a CRT spot size of 0.0005 inch that the resolution estimate had been optimistic, and the task of optimizing the optical and electrical response of the recording system was going to be troublesome. Furthermore, once the film types (viz., Plus-X Pan and Plus-X Aerographic) had been established, the lens aperture could be reduced to as low as f/5.6, with f/4.5 being about ideal. At 1:1 projection these apertures become f/11.2 and f/9, respectively, and the depth of focus increases to at least

$$FR = \pm \frac{9}{50 \text{ lines per millimeter}}$$

$$= \pm 0.18 \text{ millimeter}$$

$$= \pm 0.007 \text{ inch}$$

In order to allow for possible improvement in CRT spot size and improved alignment technique, part of the structure in models subsequent to the all-Invar, no. 4 recorder was still made of Invar in order to keep the overall thermal expansion to about 0.005 inch.

Early in the initial design study for the standard optics configuration, the use of metal mirrors that were flat to an accuracy of 1/8 wavelength of green light was considered. In metal mirror design, the primary concern is not expansion (which would be slight in any case), but rather the degree of thermal unbalance between the front and rear surfaces of the mirrors. Although the reflecting surface of ordinary pyrex mirrors can become quite distorted if there is a thermal gradient between the front and back faces, a metal mirror of such materials as aluminium or beryllium comes to rapid thermal equilibrium (because of its high conductivity) and is not as subject to distortion. Such metal mirrors are generally carefully cast and finely ground. After grinding, a Kanigen (chemical deposition of nickel) coating is applied, polished to optical tolerances, and then coated with aluminum. Since this procedure is quite expensive, and it was felt that the temperature between the front and rear surfaces of each mirror should be quite stable, pyrex mirrors were used in all the recorders—but with the reservation that metal mirrors could be fabricated if it was found that the mirrors were becoming distorted at any time during operational use of the system. However, there has been no indication to date that metal mirrors are required.

After being aluminized, each of the several reflecting surfaces of the optical system was overcoated with silicon monoxide in order to maximize the reflection of blue light (4,600 Å). Scratch, dig, and other tolerances were held fairly tightly in order to minimize light scattering. The technique of referencing the first (reflecting) surfaces of the mirrors against the mounting clips made it unnecessary to maintain tight thickness tolerances on the glass, and facilitated mirror replacement.

3.2 MECHANICAL SYSTEM

Prior to initiating the mechanical design of the first recorder, a series of tests was made on various breadboard-model film transport systems. These tests clearly demonstrated that off-the-shelf components and conventional techniques were inadequate for a system in which film flutter must not exceed ±0.025 percent. The capabilities of various combinations of rollers and pacers in maintaining constant film speed were established by a frequency comparison technique in which the frequency applied to a $9\frac{1}{2}$-inch-wide magnetic film through a recording head preceding the film drive was continuously compared with the frequency picked off at a point beyond the film drive. Any frequency difference was then attributable to variations in film velocity. Attempts were also made to measure, or to make a reliable approximation of, any film flutter indicated by Lissajous patterns on the oscilloscope used in making the frequency comparison. These investigations showed that relatively advanced techniques would be needed if the desired constancy of film motion were to be achieved.

Further experiments to expose moving film from a slit of light simulating the CRT light received via fiber optics indicated the need for determining the light levels necessary in simulating the illumination provided by the CRT trace.

The establishment of film-type requirements and processing control techniques was also found necessary.

After a space factor was evolved, an attempt was made to develop a packaging layout that would be consistent with the dimensional limitations imposed by the space allotment. However, even without the inclusion of film cassettes, it soon became apparent that the required items could not possible be packaged in the available space. After the space limitations were relaxed somewhat, it was decided that the slightly larger space could be lived with if it were clearly recognized that (1) film cassettes were to be omitted and (2) the ease of film threading would be somewhat compromised by the necessary closeness of components. In order to assemble all components into the allotted space, a decision was made to accept a reduced film capacity in the event that thin base film was not procurable.

An overall design layout was urgently needed at this point. Because of the many uncertainties and a tight schedule, it was decided to use a plate-type structure in which critical holes would be initially jig-bored, and to which new components would be added as the detail design materialized. This approach allowed the design and fabrication of the outside skin—a long-lead item—to proceed. The overall layout was then divided into discrete spaces, in each of which a certain amount of design flexibility was possible so long as the overall integration was maintained.

Up to this point, the film transport was designed to provide as short a film path as possible between the supply and takeup spools. Furthermore, the CRT trace from the optical coupling array was to be exposed on the film at a point as near the pacer roller as possible, a requirement that would have necessitated precision rotating components from the beginning to end of the film transport system, since any eccentricity would mean tightening or loosening of the film tension near the exposure point. Also, any discontinuity of motion, e.g., that produced by gearing or timing belts, would have resulted in a deleterious effect on the exposure level. Consequently, a design change was made in order to isolate the exposure station from all of the transport system except that between the pacer roller and a viscous drag roller. This was accomplished by providing free loops of film whose lengths are automatically controlled at points before and after the exposure station. This approach permitted the use of less precise rotating components in conjunction with geared motors. The adoption of this concept required some modifications in the existing hardware, but fortunately the versatility provided by the plate structure allowed these changes to be easily accomplished.

During the early portion of the program, frequent changes in the specified film speed made it impossible to finalize roller diameters, motor sizes, speed reductions, and pulley configurations. However, once this film speed was finalized, these parameters were established with confidence.

The use of a red-light photocell sensor for film loop control, although initially planned, was abandoned in favor of a microswitch having a sensitive actuating arm.

Replacement of the torque motors, initially selected for their favorable weight-to-torque ratios, was necessitated by an excessive rise in the temperature of their windings at the required torque.

The impracticability of using simple edge-type film guides was evident from the start of the design, since there were two free loops of film to control and the film is of the unperforated type.

Both the initial design calculations and the performance tests showed that with an axially fixed, rotating guide on one end of the viscous drag roller, and an axially fixed, spring-loaded rotating guide on the other end, edge friction of the film against the fixed guide due to spring axial pressure caused a vibration or rippling of the film which would prevent the attainment of uniform film motion. The spring-loaded feature was then removed and the film allowed to float between two axially fixed, rotating edge guides having an acceptable tolerance between them. This system worked well, particularly when a contact roller above the drag roller was set at the correct film entrance angle and float clearance to allow the film to float between the edge guides. By controlling the frictional drag of the film driven roller as it rotated through a viscous fluid, it was possible to maintain a constant film tension at the exposure station while allowing the film to float between (but not over) the tapered edge guides. Later, this drag roller proved to be a convenient location at which to add a film motion transducer.

In an attempt to meet the severe restriction on weight, margin rollers operating near the film ends were tried. However, this method was abandoned because tracking difficulties and buckling made it impossible to run any film. A change to continuous rollers solved these problems.

Edge guides are usually located at the two points furthest from the film spools. Since in the High Resolution Radar Data Recorder the exposure station is at one such point, it is not practical

to edge guide because of the deleterious effects produced on film motion uniformity. The second film loop was therefore selected as the location for the guide. As various areas came into focus, a more intensive scrutiny of critical film drive components revealed that the control of film flutter to the specified maximum of ±0.025 percent would require that the drive roller (or pacer) and the complete pulley system meet concentricity tolerances on the order of 20 to 50 microinches. In theory, this order of precision would necessitate a "clean room." However, the pulleys and capstan were successfully fabricated to this tolerance, and assembly techniques were developed for utilizing those items already fabricated.

When such subassemblies as the trace viewing microscope, optical coupling array, CRT, and data projection system were integrated into the recorder, repositioning of previously incorporated components was necessary.

Of the main components, the CRT and optical coupling array posed particularly difficult design problems. Provisions for adjusting the CRT and its yoke, for assembling the yoke to the CRT, and for obtaining optimum magnetic shielding, were related problems which affected the arrangement of components within the recorder. Since the fiber optics array was the part having the longest leadtime, a space factor was established for it so that the balance of the design could proceed. Although a completely satisfactory array was not achieved, no appreciable difficulty was encountered in optically coupling an array to the CRT.

To enable the measurement of the CRT light levels, a photocell compartment was machined into one fiber optics array. This feature was retained in the first optical recorder, and was ultimately expanded into the present automatic brightness control (ABC) assembly. An improvement in the first few sets of fiber optics arrays was started as a retrofit kit, and a series of drawings and replacement parts were created for this purpose. However, this effort ceased when the optical recorder proved superior to the fiber optics version. Since the first CRT assembly had been designed and fabricated with only a single-layer magnetic shield, a second shield for the tube was fabricated as a retrofit kit. However, the latter was never tested, because the fiber optics recorder was discontinued. A substitute GE tube was tested and, to keep pace with the testing, the support framework for the tube and yoke was modified to accept either a Westinghouse or a GE tube. This effort also ceased when performance difficulties were encountered with the GE tube.

Meanwhile, the design of several vibration isolation systems was in progress. The types of systems ranged from four low frequency vibration absorbers (weighing a total of 80 pounds) to a scissors jack concept. A conventional center-of-gravity suspension system was also designed. This system, which allowed testing to proceed with various types of standard vibration isolators, was considered to be the most practical solution available until more data on the recorder's overall capabilities could be obtained. Since in this approach the isolators were located outside the recorder, the best possible use could be made of the limited space within the recorder, and internal modifications would not be necessary if the loading at each point of support should vary. It was unfortunate that the space envelope did not allow more width between the isolators, as the greater stability and increased isolation would have been desirable.

Considerable time and effort was expended in developing a data projector for producing an image of a 24-hour watch and a data card on the moving film. Selection and testing of the required components preceded the design of the final projector package. Some concern was felt when it became necessary to use the full adjustment range of the lens in order to focus the image on the film, but this range was found to be sufficient, and redesign of the system optics was not required. Ultimately, it was discovered that the focal length of the lens had been changed by the manufacturer from 18 to 23 millimeters, without assigning a new catalog number.

By changing the direction of the clock's winding stem, it was possible to wind the clock without opening the recorder. Another improvement (on a later projector) placed the entire data card and watch outside the recorder. This was possible only after it was proven that projection could

be made on the rotating surface of the capstan. It also meant using a longer focal length lens and incurred a 1/4-inch displacement of the image from its originally specified position on the film.

After the three fiber optics projectors had been completed, a change of scope of the contract stipulated that a multiple lamp, aircraft velocity indicator be incorporated. After the indicator was designed, built, and installed, it was found that insufficient illumination was available for exposing the velocity lamps onto the film by means of the data projector lens. The velocity indicators were therefore repackaged and relocated to permit their light to directly expose the film.

After the third fiber-optics recorder was completed, it became evident that the fiber optics approach would have to be abandoned because of unsolvable problems in the fabrication of the fiber array. The alternative approach—use of standard optics—posed a serious space problem. An additional length of $5\frac{3}{4}$ inches, but no change in width or height, was finally authorized by Westinghouse. Calculations showed that the depth of focus with the optics used at its design relative aperture maximum of f/2 was approximately ±0.002 inch. To test the feasibility of the standard optics recorder with such a small depth of focus necessitated a low coefficient of expansion, Invar mountinc structure for support of the optical components in the system. Ultimately, the feasibility of operating the system at f/5.6 relieved the tightness of the tolerances imposed by this depth of focus, and permitted the use of an aluminum frame having Invar inserts for support of the optics. The net result of this series of changes was a lighter weight recorder in which the expansion along the optical path was limited to ±0.005 inch under a temperature change of 70°F.

In the earlier portion of the recorder program, provision was made for a fan which would operate before, but not during, the actual photographic run. (Its use during the run would introduce vibrations on the film record.) The weight and complexity of this fan ultimately led to its elimination in favor of outside cooling during preflight warmup at the flight line.

Also eliminated as the program progressed was a velvet pressure pad whose purpose was to improve the system resolution by keeping the film in more intimate contact with the exposure trace of the fiber optics. This pad was not required in the standard optics recorder because the exposure was onto a film drive capstan, rather than a fiber faceplate.

3.3 ELECTRONIC SYSTEM

The logic portion of the CRT horizontal deflection circuit uses conventional flip-flops to convert the 40-nanosecond, 10-volt synchronizing pulses from the radar into square waves that drive the CRT deflection circuit. The nature of the scan on the face of the CRT is unusual in that the symmetrical triangular wave of beam-deflection current is not only required to drive the beam first in one direction across the screen and then return it to its starting point at the same rate, but must also be synchronized with another current waveform applied to the horizontal deflection coil in order to step the trace sideways for the return sweep.

During the program, the design of the deflection yoke driver went through several stages. The first attempt, a breadboard based on a vacuum tube circuit incorporating current feedback to maintain linearity of the triangular deflection current, proved successful. However, since the overall design philosophy was to use transistors wherever possible, particular emphasis was given to the development of a transistorized version of a triangular current generator and yoke driver. Early experiments led to a type of free-running generator which was capable of driving the yoke directly, but this approach was later abandoned in favor of a driven circuit.

In attempting to design a driver-type transistor circuit that would provide a symmetrical triangular wave of current for the horizontal coil of the CRT deflection yoke, several techniques were tried. To achieve as linear a current waveform as possible, the first approach was to build a bootstrap circuit that provided a very linear triangular voltage waveform. Although such a waveform was readily achieved, the attainment of an equally linear current waveform in a magnetic deflection yoke was found difficult.

Fig. 3-1a shows the desired current waveform in the horizontal deflection coil. In the ideal case, this waveform consists of a current that increases at a constant rate ($di/dt = K$) until the current reaches the positive value required to produce maximum deflection of the beam. At this time, the direction of current flow is reversed, $di/dt = -K$, and the current decreases, passing through zero to a peak of $-I$ to deflect the electron beam to its maximum in the opposite direction. Figs. 3-1b and 3-1c show the voltage waveforms that exist across the yoke inductance and resistance, respectively, under these conditions; these waveforms are functions of the L/R ratio (i.e., the time constant) of the coil.

Since the voltage across the inductance is $E = L\,di/dt$, and di/dt is allowed only two conditions ($+K$ and $-K$), it follows that E is equal to $+KL$ or $-KL$. For best linearity across a yoke that inevitably includes a finite series resistance as well as inductance, the waveform must be that shown in Fig. 3-1d. In this plot, the tilt in the normally horizontal portion of the voltage square wave represents the voltage required to drive a triangular waveform of current through the yoke resistance. With a high value of L/R, a triangular current waveform can, in general, be produced in an inductance by switching the voltage that appears across it. The resulting current waveform is exponential, but by making the time constant of the yoke much greater than the scan period, a high degree of linearity can be maintained.

In the case of the recorder, the initial design attempts were based on the use of a 28-volt power supply; however, the poor regulation of this supply, and the availability of transistors that would operate with collector-to-base voltages of 60 to 80 volts, made it advisable to use a well regulated, 60-volt source that was already available in the system.

In the recorder application, the period for a full scan is 250 microseconds. The slope of a triangular current waveform is $2I/(T/2) = 4I/240 \times 10^{-6}$ second, where I is the current required to deflect the CRT beam from the center of the tube to one side.

If it is assumed that $E_L = 50$ volts peak-to-peak, then

$$50 = E_L = L\,di/dt$$

Since di/dt is a constant in this application, its value can be calculated from known values of I and t, where t is the time allowed for the current to rise from zero to maximum value (at the end of 1/4 cycle). Therefore, $t = 250/4 \times 10^{-6}$ second, or 62.5×10^{-6} second.

Since

$$di/dt = I/t$$

$$L\,di/dt = LI/t = 50$$

$$LI = 50 \times 62.5 \times 10^{-6} \text{ henry-amperes}$$

$$= 3.12 \times 10^{-3} \text{ henry-amperes}$$

In the design of deflection yokes, other things being equal, the product of LI^2 is a constant, an assertion that is supported by yoke data published by manufacturers.

If $LI^2 = K$, the value of K for a practical yoke should be in the range of 0.001 to 0.0005 henry-amperes^2. For a yoke inductance in this range, the above equation shows that the design should be such as to provide a current of more than 0.5 ampere.

The foregoing considerations led to the choice of a Celco yoke having a 3-millihenry inductance and a nominal resistance of 3 ohms. This yoke requires a current of 0.58 ampere to deflect

a 20-kilovolt beam from the center to the edge of a 21-degree tube. If a 15-kilovolt beam is used, the required yoke current can be computed from the relationship

$$I_{15kv} = I_{20kv} \sqrt{\frac{15 \times 10^3}{20 \times 10^3}} \text{ volts}$$

$$= 0.58 \text{ ampere} \times \sqrt{0.75}$$

$$= 0.58 \text{ ampere} \times 0.866$$

$$= 0.50 \text{ ampere}$$

A number of circuits were tried in which current feedback was utilized to linearize the current waveform. Although these circuits worked with varying degrees of success, none could provide sufficient deflection without exceeding the allowable dissipation of available power transistors.

Fig. 3-2 is the characteristic curve of a transistor with the supply voltage, E_{cc}, and the maximum current, I_{max}, indicated. With a resistive load, the load line would be a diagonal from the point I_{max} at low voltage to the point E_{cc} at leakage current. In this case, the operating points are always within the dissipation limits. With an inductive load operating between these extremes, the load line is the dotted square. During the second alternation of any cycle, the voltage across the transistor is approximately $2E_{cc}$, the current decreases from I_{max} to zero, and the transistor must dissipate a relatively large amount of power. From the characteristic curves, the peak power (at the point labeled $2E_{cc} \times I_{max}$) is far into the overload area. Thus, to prevent overloading it would be necessary to choose a transistor that can dissipate this amount of power. However, this approach is not only economically undesirable, but transistors in this category have a very poor frequency response.

The ideal circuit for such an application is one in which the transistor only passes current when the voltage across it is very low. In other words, the transistor should be operated as a switch in this type of application.

Consider the circuit shown in Fig. 3-3. If it is assumed that the switches can be reversed instantly, Fig. 3-4 shows the current waveform that would be obtained as the switches periodically reverse the direction of current flow. With either polarity the current in the inductance attempts to rise to a value equal to E/R. With the 3-ohm Celco deflection yoke and a 50-volt power supply, the maximum current (equal to E/R) may be 10 or 20 times the 0.5-ampere maximum current required for full 21-degree deflection of the CRT beam.

The rise time, t, in the yoke can be computed as a percentage of E/R. Thus

$$I = E/R\left(1 - e^{-Rt/L}\right)$$

where I, E, R, and L are the coil current, voltage, resistance, and inductance in amperes, volts, ohms, and henrys, respectively, and t is the time in seconds. When $t = L/R$, the rise time is equal to one time constant. In the present instance,

$$L/R = 3 \times 10^{-3} \text{ henry/3 ohms}$$

$$= 10^{-3} \text{ sec}$$

The scan period, as computed above, is 0.062×10^{-3} second, or 1/16 of the time constant. If the period of the switching is made equal to 1/16 of the L/R time constant, the current waveform in the horizontal deflection coil is practically linear.

The circuit configuration finally chosen on a basis of the foregoing considerations is shown in Fig. 3-5. The power in the yoke circuit is largely reactive, i.e., it exists in the magnetic field of the horizontal deflection coil, the capacitors, or the power supply. In this circuit, the action of the two transistor switches is controlled by a square wave that is applied to the bases of Q1 and Q2 through a transformer. As a result, the current reversals in the yoke are synchronized with the driving pulses to provide an efficient driving circuit for horizontal deflection.

The circuit used for the step scan (vertical deflection) current waveform is similar to that used for horizontal deflection, but the requirements for the yoke design are quite different. Since it is desirable to step the spot from its forward trace position to its return position with a minimum of lost time, the current waveform for the step scan is a square wave. The rise time of the step scan deflection coil should be as small as possible. An anomaly exists with respect to yoke sensitivity. This parameter is defined by the ratio D/I, where D is the deflection angle and I the current. The problem is to provide sufficient inductance to deflect the spot the required distance, but not enough to prevent the deflection of the spot in the extremely short time allowable for this operation.

The solution was to use a 0.1-millihenry coil whose sensitivity was equal to 0.008 degree per milliampere. If a deflection distance of 0.2 inch on the face of the 21-degree face CRT is assumed, the maximum deflection angle is ±1.0 degree and the required current is then

$$\frac{1 \text{ milliampere}}{0.008 \text{ degree}} \times \pm 1.0 \text{ degree} = \pm 125 \text{ milliamperes}$$

or 250 milliamperes peak-to-peak. To ensure sufficiently fast switching, the L/R ratio is reduced to the smallest practicable value by adding a 240-ohm resistor in series with the step scan coils. The resulting yoke current is 250 milliamperes peak-to-peak.

The rise time of the step scan yoke may be computed from the equation

$$t = L/R$$

from which

$$t = \frac{0.1 \times 10^{-3}}{2.4 \times 10^{2}} = 0.42 \text{ microsecond}$$

the time required for the current to reach 63 percent of its ultimate value. It will reach 99 percent of this value in five L/R time constants, i.e., 2.1 microseconds. The ratio of total sweep time to the half period for the scanning cycle is 2/125, or 1.6 percent.

Design Considerations (HVPS)

Filtering and shielding are necessary in order to minimize the effects of ripple and magnetic radiations originating in the high voltage power supply. In order to reduce even more the degration caused by residual noise, the inverter frequency must be locked to the fundamental sweep frequency. Of two designs investigated, the design that incorporates a free running multivibrator synchronized to the basic sweep rate is more reliable than that adopting a direct drive for the amplifier of the inverter. Loss of drive in the former causes no power supply failures, but loss of drive or change of frequency in the latter can cause the power supply to fail.

The final supply is a hybrid design using both tubes and transistors, rather than transistors only. Even though a high voltage supply composed entirely of solid-state components can be more efficient, weigh less, and occupy a smaller space, the hybrid design has provided a more reliable

unit, and one that can tolerate more of the transients and malfunctions originating at the aircraft/recorder interface.

Since the focus of the WX4903 tube must be maintained by holding the ratio of ultor voltage to focus voltage constant, a ratio network was used to force the supply to track with any change in ultor voltage. This technique improved the temperature regulation of the unit by a factor of 10 or more.

The use of a demountable sideplate heat sink rather than hermetic sealing permitted better accessibility to internal components and easier maintenance of the supply during field use.

3.4 PHOTOGRAPHIC DESIGN

Selection of the film to be used with the recorder was part of the recorder design. The film characteristics studied were the speed of the emulsion when exposed to the CRT, processing characteristics, and resolution.

The video signal applied to the grid of the CRT is bilateral, i.e., the signal assumes positive or negative values around an average level. The average value of signal and the bias setting of the CRT are the same when no modulation is applied to the CRT grid. The intensity of the CRT at this bias setting and the sensitivity of the recording film establish the average transmission for unmodulated light for a specified gamma. System requirements make it desirable that the average film transmission be reasonably close to the 50 percent transmission of the film, or the 0.3 density point on the D-log E curve above base density, to avoid nonlinearity in the toe region; this exposure was set to produce an average density of 0.6 ± 0.5.

For good dynamic range, sufficient light must be available at the 100 percent modulation point to expose the film to a density of 1.5 or better, as measured from the base density.

These two points define the film dynamic range. The 100 percent modulation point is produced by the CRT when the bias reaches the point where the CRT emits maximum light.

For sensitometer selection of the film, these two points are related to the CRT characteristics. The 50 percent film transmission exposure should result when the grid voltage of the CRT is approximately halfway between tube cutoff and maximum light output. Some leeway is allowable since in the lens recorder, adjustments of the lens aperture may be made to set this point accurately.

The characteristics of a number of different films were determined for exposures to simulated P11 phosphor illumination (see Fig. 3-6). The films evaluated were Eastman Kodak 5374 TV recording film, Kodak SO-130 (Aero Pan-X), Kodak 30-52647, Kodak Electrocardiograph, Ilford BY, Ansco Hyscan, Kodak 4401 (Aero Plus-X), Kodak SO-243, Kodak 5427, and Kodak Tri-X Pan. Since previous tests had indicated that 5374 was approximately three stops (eight times) too slow, the investigation was to determine what films would be suitable for use in the lens recorder. The object of this investigation was to find a film that was eight times faster than 5374 when exposed to the illumination of a CRT coated with P11 phosphor (see Fig. 3-7). The maximum high (1,000 to 1) and low (2 to 1) contrast resolving power capabilities of 5374 and the two fastest materials tested (4401 and Tri-X Pan) were also determined to indicate how much of a resolution sacrifice must be made in order to achieve sufficient sensitivity.

Tri-X Pan was the only film tested that produced an 8× speed increase over 5374. It actually measured to be 30 times (five stops) faster; however, the fog level (0.34) is sufficiently high to be considered detrimental. Kodak Plus-X Aerial film, 4401, the next fastest material, was 4.4 times faster than 5374. Tests made in the recorder showed that this film could be exposed to the WX4903 CRT at a lens stop of f/5.6 (marked aperture) with satisfactory results.

Table 3-1 lists the films tested in order of sensitivity relative to 5374 TV recording film.

The results of the resolution tests (listed in Table 3-2) show the sacrifice that must be made in order to use the higher speed films. Type 4401 has only 65 percent of the high contrast and 42 percent of the low contrast resolving power of 5374. The high contrast resolution of Tri-X Pan is only 48 percent of 5374, and the low contrast resolution is only 37 percent.

The film finally selected for the lens recorder was the Kodak type 5401 Plus-X Aerographic film. This film is similar to type 4401, except for the base material which for 5401 is 5.2-mil acetate butyrate without gel backing. Film type 4401, which was obtainable at that time only on special order, uses a 2.5-mil Estar polyester base with a gel backing.

Table 3-1 — Films Tested in Order of Sensitivity Relative to 5374 TV Recording Film

Film*	Speed Relative to Eastman Kodak 5374 (at density = 0.6)
SO-243	0.13
5427	0.5
5374	1.0
SO-130	1.7
30-52647	1.9
Electrocardiograph	2.1
Ilford BY	2.3
Ansco Hyscan	2.7
4401	4.4
Tri-X Pan	30.0

* Eastman Kodak unless otherwise specified.

Table 3-2 — Resolving Power of Three Eastman Kodak Films

	Resolving Power, lines/mm	
Film	Target Contrast, 1,000:1	Target Contrast, 2:1
5374	178	105
4401	112	44
Tri-X Pan	89	39

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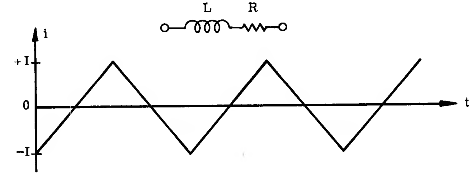
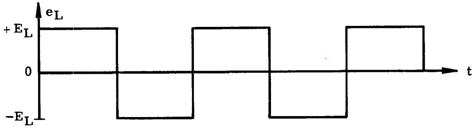
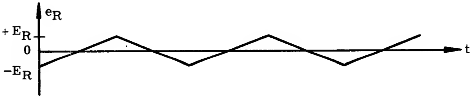


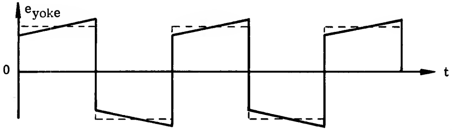
(a) Current through inductance



(b) Voltage across inductance



(c) Voltage across resistance



(d) Voltage across series inductance and resistance

Fig. 3-1 — Waveforms for horizontal deflection of CRT beam

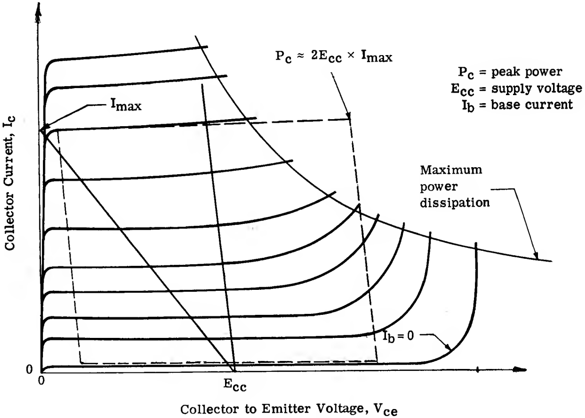


Fig. 3-2 — Characteristic curve of a transistor

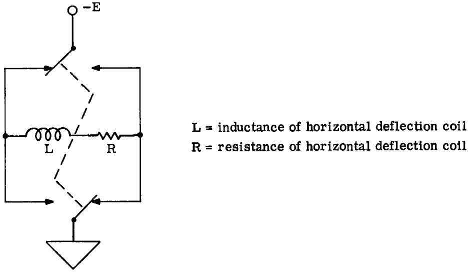


Fig. 3-3 — Triangular current generator — conceptual

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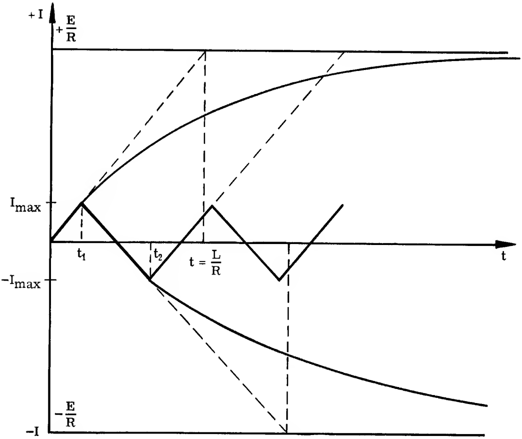

Fig. 3-4 — Waveform of linearized horizontal deflection current

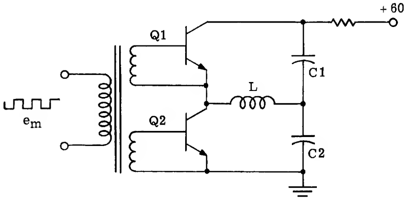

Fig. 3-5 — Schematic of transistor switching circuit for producing triangular current waveform in horizontal deflection circuit

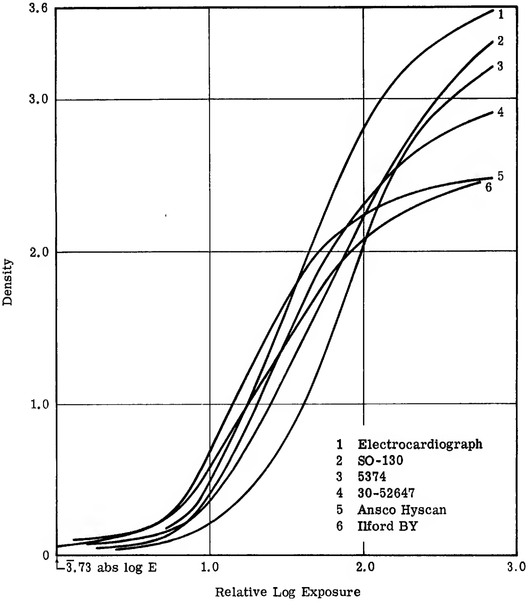

Fig. 3-6 — Comparison of film characteristics determined for exposures to simulated P11 phosphor illumination

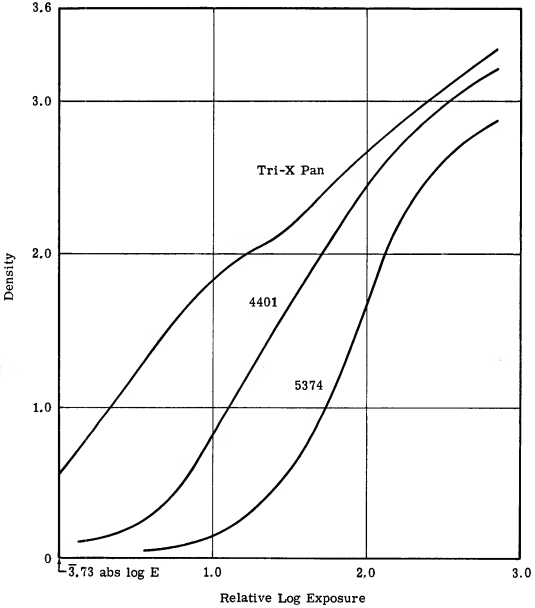

Fig. 3-7 — Comparison of Tri-X Pan and 4401 films with 5374 film

4. RECORDER PERFORMANCE

The following data on the High Resolution Radar Data Recorder reflects the performance level achieved at the completion of the original program. These data fall into four general classes: (1) mechanical, (2) optical, (3) electrical, and (4) photographic. Additional data will be forthcoming shortly, as a result of the follow-on evaluation program now in progress.

The performance of the recorder is determined ultimately by the quality of the film recording, i.e., the fidelity with which the radar-video input signal is converted to high resolution density variations on the film. Degrading factors whose elimination has required, and still requires, strenuous analysis and experimental efforts are: electronic noise, acoustic noise, vibration, hum, and jitter of the scanning beam.

From work to date on the recorder program, it is clear that in many areas conventional methods for determining performance are inadequate for a system in which state-of-the-art capabilities must be significantly advanced. One aim of the evaluation program is to establish suitable techniques for evaluating recorder performance with the required accuracy. One technique uses moire patterns to disclose and evaluate the magnitude of small variations in film transport velocity, and has been successfully employed during the latter portion of the program and during the evaluation study now in progress. This technique is briefly discussed in a following subsection of this report.

4.1 VIBRATION SHOCK MOUNTING

The vibration isolation effectiveness of three types of shock mounts was evaluated by subjecting the recorder to the vertical-plane vibration loadings specified by MIL-E-5400 and the specific requirements of Westinghouse specification R-1811. The isolators tested were: (1) a Barry compression type, (2) a Lord compression type, and (3) a Lord shear type. As is shown by the curves of Fig. 4-1, the Lord J-8350-7 and -8 shear-type mounts showed a marked superiority to the other mounts in isolation effectiveness over the frequency range of 60 to 180 cps. These plots were prepared from the accelerometer readings of Tables 4-1, 4-2, and 4-3 for the three types of mounts investigated.

Computations from these data show the following capabilities for the three types of vibration isolators:

Type of Isolator	Vibration Isolation, percent
Lord shear-types J-8350-7 and -8	96.5
Lord compression-type J-7148-61	86.5
Barry compression-type L64-X44	79.8

The results of the vibration analysis were compared with point-source film traces that were recorded during the vibration testing. The light source for these traces was a 75-watt bulb—used in place of the CRT in order to eliminate the effects of undesired magnetic fields on the CRT trace. The illumination source was enclosed by a light housing in which two pinhole openings at the object plane produced a 10-mil-diameter spot at each of the two trace positions. In Fig. 4-2 the light-spot trace obtained with no vibration input is compared with that for each of the three mounts at representative vibration frequencies of 120, 160, and 200 cps. As is seen, the trace from the Lord shear-type mount shows less vibration modulation at all three frequencies than that for the other two mounts. The complex motion of each spot as a result of the vibration inputs acting on it through the optical lever was considered to be caused by one or by both of two effects:

1. External vibrations that were not filtered out by the vibration mounts

2. Individual and combined motions of recorder components. Since the optical technique for vibration detection cannot disclose individual vibration sources or their magnitudes, an acoustic method was used (1) to accomplish this part of the investigation, (2) to localize noise originating in rotating components, and (3) to quickly evaluate the probable effects of contemplated design changes.

In this experiment, the vibration excitation was provided by a small loudspeaker attached directly to the bearing plate of the recorder. The output of an accelerometer that could be readily moved to any suspect component was fed to an oscilloscope as the vibration excitation was applied. A filter with adjustable bandpass was used to isolate and determine the predominant vibration frequencies.

Visual and photographic evidence from these tests indicated that the maximum responses, occurring at frequencies of 218 and 285 cps, were the result of vibrations from various points on the recorder sideplates, andfrom any elements, e.g., the lens board and tie bars, connecting them.

In an attempt to correct this condition, the lens mounting and M3 mirrors were isolated from the lens board by several layers of a cork-rubber material. Although no improvement was noted for frequencies below 300 cps, a layer of this material placed between the motors and the sideplates provided, in conjunction with nylon mounting screws, a noise reduction of approximately 50 percent. Despite this improvement, the residual noise from the motors was still carried through the plates to the lens board, the lenses, and the M3 mirrors. This vibration level, although of a low order, is still higher than acceptable, and will require a continued effort to find a solution.

After achieving the best possible isolation between motors and sideplates, the accelerometer used as a vibration probe was placed on the sideplate in an orientation that would measure the peak-to-peak vibration displacement along the optical path for 485-cps excitation. This vibration frequency was found to be the predominant one (under 1,000 cps) by feeding the accelerometer output to a spectrum analyzer.

4.2 THERMAL EFFECTS DURING 3-HOUR OPERATING PERIOD

Thermal excursions occurring within the recorder during a 3-hour period of sustained operation were determined by operating the shock-mounted equipment with its light covers in place. A 75-watt light bulb with reflector pointed upwards was used to simulate the normal (70-watt) heat dissipation of the high voltage power supply. To simulate the heat developed by the film transport system, the torque motor was locked. In all other respects the recorder was energized and operating at a nominal total input power of 242 watts.

To sense the thermal variations occurring during sustained operation, two thermometers and a thermocouple were used. One thermometer was located near the capstan; the other was located external to the recorder in order to monitor the ambient temperature in the immediate vicinity of the equipment. The thermocouple was bonded to the top surface (front panel) of the deflection and logic assembly at the transistor heat sink.

Curve 1 of of Fig. 4-3 shows that the temperature at the transistor heat sink of the deflection and logic assembly reached 110°F after 135 seconds of recorder operation, but did not increase thereafter. The temperature in the immediate vicinity of the capstan (see curve 2) was lower after 60 minutes than that (see curve 3) of the outer surface of the top cover at a point above the capstan. This effect is explained by the presence of a cooling fan (part of the hysteresis motor) located near the capstan. The shape of curve 3 indicates that the light covers are not thermal insulators and hence conduct heat away from the sideplates for radiation to the lower temperature atmosphere outside the recorder.

4.3 FILM TRANSPORT SYSTEM

One of the primary requirements in the design of the High Resolution Radar Data Recorder was that of maintaining extremely accurate control of film velocity. The sources of film velocity variations isolated during the program were (1) small departures from true concentricity in the rollers, bearings, and pulleys, and (2) small variations in the thickness of the drive belts.

In evaluating the constancy of film motion, an input frequency of 100 cps is recorded on a number of feet of film. After the film is processed, it is cut laterally into two pieces of equal length. When one piece is placed on top of the other, a moire pattern is formed. This pattern is a visual presentation of the beat frequency corresponding to variations in film velocity during the film run.

Fig. 4-4 shows a representative moire pattern in which each cycle of the beat frequency covers a distance of 0.7 inch along the time axis of the film. After a faulty idler roller was replaced, a subsequent test yielded a moire pattern in which one cycle of the beat frequency covered 7 inches along the time axis. The latter result indicated a speed variation of only 0.14 percent over a 7-second interval, i.e., an average variation of only 0.02 percent per second.

This type of moire interference test was made on each recorder prior to acceptance testing and delivery.

In the course of evaluating the constancy of film transport velocity, it was found that the metal pulleys when magnetized by stray fields in the recorder caused degradations in system resolution by deflecting the CRT beam. An interim correction of this problem was to use degaussing techniques, but a more basic approach—that of finding or developing a nonmagnetic pulley having satisfactory mechanical qualities—was planned as part of the follow-on program for evaluation of the recorder.

4.4 HIGH VOLTAGE POWER SUPPLY

The important parameters in the performance of the recorder's high voltage power supply are (1) the constancy with which a desired ratio between the ultor voltage and the focus voltage can be maintained, (2) the day-to-day repeatability of output voltages obtained at any ratio within the ratio range provided, and (3) reliability.

A conservative interpretation of results obtained during repeated tests with the Kaiser DDM4KV1 power supplies in four recorders has given the performance data shown in Table 4-4. In the Kaiser supply, the ratio of ultor voltage to focus voltage can be varied from 3.360 to 3.810 by means of the focus control. Ripple frequency and the frequency of the magnetic radiation are locked to the 3.92-kilocycle sweep frequency in order to minimize their effects on the output voltages of the supply.

Fig. 4-5 is a graph showing the results of representative phase II acceptance tests—those on Kaiser supply no. 9889 on 6 and 9 December 1963. The curves of the figure show the closeness with which the ratio of ultor voltage to focus voltage is maintained over a 90-minute period following a 30-minute stabilizing interval. As is seen, the maximum variation measured in the first

test was 0.014 percent, and in the second test was 0.02 percent. Day-to-day repeatability, based on the maximum variation in the ratio of ultor voltage to focus voltage for the combined periods of test, was within 0.02 percent.

The graph of Fig. 4-6 shows the baseplate temperature as a function of time for a room ambient temperature of approximately 26.5 °C (79.7 °F). Since the high voltage power supply is a sealed unit, most of whose internal test points are at high potential, it is difficult to sense the internal temperature. The external temperature of the baseplate, while an accurate indicator of the average internal temperature, does not indicate hotspot temperatures within the case. As is seen from the figure, baseplate external temperature increases with operating time, reaching equilibrium at approximately 65 °C (149 °F) after 2 hours of continuous operation.

The curves of Fig. 4-7 show, for no load and full load conditions, the change in the ratio of ultor voltage to focus voltage as the input voltage to the power supply is varied over the range of ±3 volts from the nominal value of 28 vdc. From the data used in constructing the curves, the line regulation and load regulation of the Kaiser supply can be determined. For a given input voltage, load regulation is defined as $\Delta R/R_{min}$. Here R is the change in ratio of ultor voltage to focus voltage associated with a change from no load to full load. Line regulation is defined as the change in $\Delta R/R_{min}$ associated with a given change of input voltage. Calculations based on a conservative interpretation of data from four Kaiser supplies show that the load and line regulation are at least ±0.002 percent and 0.12 percent, respectively.

As is seen from Table 4-4, the line regulation, although meeting specifications, is the only functional parameter that does not actually exceed the design goal established for it. Although the regulation of the ultor portion of the ultor-focus supply is excellent, that of the focus portion is only 1/6 as good. The latter is therefore the dominating factor in the overall deviation of the ratio of the ultor voltage to focus voltage. In system operation, the line regulation of the ultor-focus supply is improved by the use of a buffering 28-vdc supply that is regulated to ±0.5 percent.

4.5 AUTOMATIC BRIGHTNESS CONTROL (ABC) UNIT

The ABC unit of the recorder compensates, over a wide dynamic range, for brightness changes (at the screen of the CRT) caused by variations in the tube's electrode voltages. Fig. 4-8 shows that with the ABC circuit disabled, a change of 14 volts at the control grid of the CRT will change the screen brightness by a factor of 100:1. With ABC feedback introduced, this variation is reduced to a mere 1.71:1.

The ABC circuit is also used to compensate for low frequency brightness fluctuations at the CRT screen as a result of variations in the voltage applied to the G2 electrode. Fig. 4-9 shows that a brightness change of 9.1:1 (caused by a variation of 50 volts at electrode G2) is reduced by ABC action to a change of only 1.32:1.

The ABC unit meets the design goal of controlling CRT brightness to the extent that a 2:1 variation in screen brightness as a result of variations in CRT electrode potentials is limited to a brightness change of only 1.1:1.

4.6 CRT SWEEP LINEARITY

In order to achieve as linear a triangular sweep as possible, the sweep circuit was designed so that a small, nearly linear portion of the curve shown in Fig. 4-10 is reproduced in the deflection of the CRT beam. The equation for the overall curve is $y = (1 - \epsilon^{-x})$.

Fig. 4-11 compares that portion of the curve used for the sweep waveform with a straight line whose equation is $y = 0.945x$. Corresponding y values for the straight line, and for the sweep curve, are shown at each 0.02 point in the X-axis direction. The time constant of the sweep (125 microseconds) when compared with that for the yoke (1,150 microseconds) gives a proportionality

constant of 0.109. Fig. 4-12 is a plot of spot deflection versus yoke deflection current. Yoke resistance was 3 ohms. The deflection current was obtained by measuring the voltage drop across a 1-ohm, 50-watt Dale resistor whose temperature coefficient was 20 parts per million. This resistor was mounted on a finned heat sink in order to minimize any low order temperature effects. A Fluke differential-type instrument was used to read millivolts, and a Gaertner traveling microscope was used to read distance to the nearest thousandth of an inch. From this data it is possible to determine sensitivity, using the following expression

$$\%L = \frac{S_{max} - S_{min}}{S_{max} + S_{min}} \times 100$$

Substituting values, this expression becomes

$$\%L = \frac{4.15 - 4.00}{8.15/2} \times 100$$

$$= 3.68$$

In the equation, maximum sensitivity is that at 16 degrees off axis (2 inches from the center of the tube), and minimum sensitivity is that at 2.5 degrees off axis. The measured linearity of 3.68 percent agrees closely with the theoretical value of 3.7 percent for 16-degree deflection on a flat-face tube used in conjunction with a yoke of uniform field.*

A plot was made of the triangular current waveform as measured by using the delayed sweep feature of a Tektronix 545A oscilloscope. The scope was calibrated to 0.2 microsecond per division on the Helipot time-base multiplier. Readings were taken on the Helipot and real time calculated from these readings. The current amplitude was measured to an accuracy of 10 milliamperes, using the Tektronix current probe and adjusting the vertical amplifier gain to as high a value as the scope centering controls would permit. Fig. 4-13 shows a current versus time plot of the data obtained. A straight line is drawn from the origin to the point indicating the end of the sweep at 125 microseconds. The individual plotted points, when connected, clearly show the actual current waveform. The maximum departure from linearity at point A is seen to be 40 milliamperes. Taking this as a percentage of full amplitude, the maximum percent departure from a straight line is 40/1,000 = 4 percent.

A measurement of sweep-rate linearity was made by using a dot pattern generated on the CRT by a gated high frequency oscillator. The measurements were made by counting 10 dots and measuring the corresponding distance with a Gaertner traveling microscope.

It was found that the average distance was 64 mils for 10 dots. The deviations from the average value of 64 mils are plotted in Fig. 4-14 for each 10-dot increment. No measurements were made on the fiber optics section of the CRT at the tube center. From this plot, the maximum linearity was calculated as ±14 percent. It should be noted that all these measurements were made with the centering coil strapped to ground in order to eliminate stray noise pickup due to the coil. It should also be mentioned that the circuit used was a breadboard version of an approach to reducing the overall delay time from the input sync pulses to the start of the trace. In order to obtain fast switching times, high speed silicon transistors were used. Although these components materially reduce delay times, they have a slightly higher saturation resistance than germanium transistors and thus can degrade linearity slightly. This breadboard circuit also uses a speed-up capacitor across the series resistor in the primary of the driver transformers. Since a 60-volt

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*Technical Documentary Report ASD-TDR-62-739, High Resolution Cathode Ray Tube, P.58.

amplifying switch was eliminated between the sync flip-flop buffer and the drivers, this capacitor is required in order to obtain sufficient current drive for the deflection.

Two types of error are encountered in the design of a triangular–scan deflection circuit: (1) spot displacement error and (2) incremental or scan-distortion error. Fig. 4-15 shows these effects graphically. The spot displacement error is computed as 3.68 percent. Fig. 4-15 shows that the spot displacement error when translated to distance measurements results in a scale distortion error of approximately 15 percent. Thus at the far end of the scale the distance representing 1 mile on the "actual" scale is 15 percent greater than it would be with perfectly linear deflection.

Table 4-1 — Vibration Transmissibility of Lord Shear-Type Mount

Forcing Frequency, cps	g_{out}/g_{in} Mount 2	Mount 3	Mount 4	Mount 5	Average
10	1.57	1.10	1.35	1.35	1.34
15	1.12	0.76	0.54	0.44	0.72
20	0.57	0.49	0.43	0.34	0.46
25	0.13	0.18	0.27	0.17	0.19
30	0.13	0.13	0.22	0.14	0.16
35	0.39	0.25	0.34	0.35	0.33
40	0.28	0.18	0.26	0.25	0.24
50	0.13	0.08	0.14	0.12	0.12
60	nil	0.01	0.06	0.04	0.03
70	0.01	0.01	0.05	0.02	0.02
80	0.01	0.02	0.05	0.05	0.03
90	0.01	0.01	0.05	0.02	0.02
100	0.01	0.01	0.02	0.02	0.02
110	nil	0.01	0.01	0.01	0.01
120	nil	0.01	0.01	0.01	0.01
130	0.02	0.03	0.02	0.02	0.02
140	0.10	0.09	0.04	0.02	0.06
150	0.27	0.10	0.03	0.09	0.12
160	0.10	0.02	0.01	0.03	0.04
170	0.14	0.01	0.02	0.08	0.06
180	0.04	0.01	0.01	0.02	0.02
190	0.28	0.12	0.08	0.10	0.14
200	0.22	0.16	0.21	0.18	0.19
210	0.22	0.16	0.07	0.07	0.13

Note: Average was taken over forcing frequency range of 60 through 180 cps.

Table 4-2 — Vibration Transmissibility of Lord Compression-Type Mount

Forcing Frequency, cps	g_{out}/g_{in} Mount 2	Mount 3	Mount 4	Mount 5	Average
10	1.86	1.32	1.39	1.86	1.61
15	1.86	1.44	1.70	1.79	1.70
20	2.0	1.93	1.64	1.43	1.75
25	1.29	1.07	1.04	0.97	1.09
30	0.97	0.89	0.82	0.82	0.88
35	0.58	0.63	0.56	0.58	0.59
40	0.73	0.71	0.29	0.32	0.51
50	0.25	0.23	0.27	0.27	0.26
60	0.55	0.35	0.55	0.53	0.50
70	0.10	0.16	0.79	0.11	0.29
80	0.13	0.15	0.13	0.18	0.25
90	0.10	0.11	0.09	0.13	0.11
100	0.07	0.09	0.05	0.09	0.08
110	0.04	0.07	0.06	0.05	0.06
120	0.04	0.07	0.05	0.06	0.06
130	0.04	0.05	0.04	0.06	0.05
140	0.03	0.04	0.05	0.03	0.04
150	0.04	0.04	0.08	0.06	0.06
160	0.04	0.04	0.07	0.07	0.06
170	0.05	0.10	0.07	0.10	0.08
180	0.07	0.19	0.10	0.10	0.12
190	0.70	1.86	0.69	0.69	0.98
200	0.18	0.25	0.18	0.08	0.17
210	0.08	0.11	0.13	0.04	0.09
220	0.05	0.05	0.10	0.03	0.06

Note: Average was taken over forcing frequency range of 60 through 180 cps.

Table 4-3 — Vibration Transmissibility of Barry Compression-Type Mount

Forcing Frequency, cps	g_{out}/g_{in} Mount 2	Mount 3	Mount 4	Mount 5	Average
10	0.65	0.45	0.70	0.90	0.68
15	0.64	0.32	0.29	0.34	0.40
20	0.40	0.20	0.23	0.26	0.27
25	0.28	0.13	0.21	0.35	0.24
30	0.34	0.14	0.19	0.19	0.22
35	0.31	0.12	0.16	0.20	0.20
40	0.30	0.12	0.19	0.24	0.21
50	0.37	0.11	0.20	0.24	0.28
60	0.48	0.13	0.12	0.32	0.26
70	0.25	0.13	0.16	0.18	0.18
80	0.32	0.14	0.22	0.22	0.22
90	0.21	0.14	0.27	0.16	0.20
100	0.22	0.14	0.25	0.11	0.18
110	0.29	0.16	0.21	0.08	0.18
120	0.27	0.17	0.18	0.08	0.18
130	0.24	0.18	0.20	0.08	0.18
140	0.28	0.14	0.23	0.08	0.18
150	0.18	0.22	0.21	0.08	0.17
160	0.21	0.15	0.20	0.09	0.16
170	0.21	0.15	0.20	0.15	0.18
180	0.54	0.36	0.19	0.34	0.36
190	0.60	0.38	0.68	1.12	0.70
200	0.66	0.52	0.62	0.62	0.60
210	0.38	0.31	0.16	0.30	0.29

Note: Average was taken over forcing frequency range of 60 through 180 cps.

Table 4-4 — Performance Data — Kaiser High Voltage Power Supply

Parameter	Design Goal	Achieved
Weight, pounds	8	16
Size, inches	6 × 4 × 5	$7\frac{1}{2} \times 4\frac{15}{16} \times 8\frac{1}{4}$
Input power, watts	84	77
Max ambient temperature, °C	+70	+55
Voltage regulation, percent		
Ultor-focus supply		
Line	±0.1	±0.11
Load	±0.1	±0.0014
With temperature	±0.1	±0.095
G2 supply		
Line	±0.5	±0.1
With temperature	±0.5	±0.1
Ripple, peak-to-peak volts		
Ultor supply	15	8
Focus supply	4	0.7
G2 supply	1	0.2
Magnetic field strength, gauss	0.1	0.01
Life expectancy, hours	2,000	Undetermined. 400 hours logged to date, 300 hours of which was in aircraft

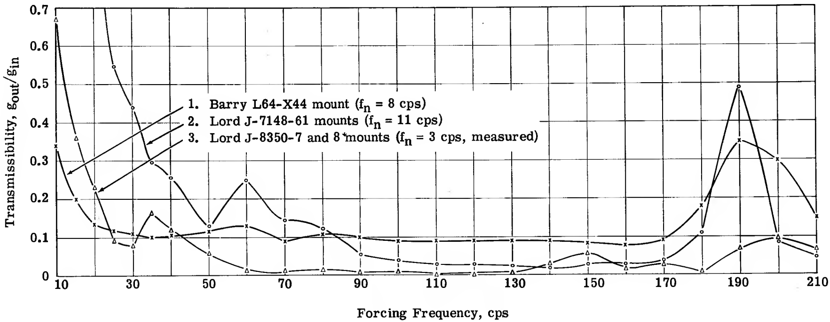

Fig. 4-1 — Transmissibility of three types of vibration isolators as a function of frequency

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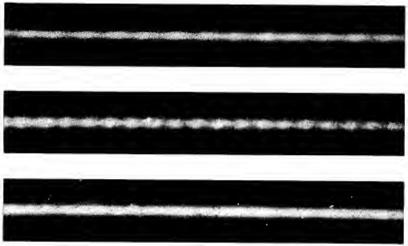
(a) Light trace with no vibration input



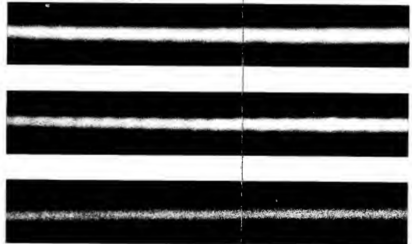
120 cps

160 cps

200 cps

(b) Light trace with Barry compression-type L64-X44 mount, at 120, 160, and 200 cps

Fig. 4-2 — Vibration modulation of 10-mil-diameter light spot trace during vertical-axis vibration tests on recorder to show vibration isolation characteristics of three types of mounts

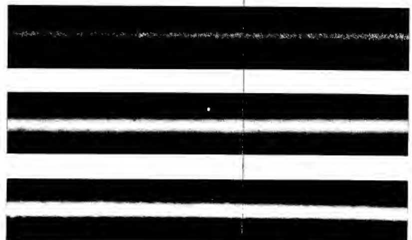


120 cps

160 cps

200 cps

(c) Light trace with Lord compression-type J-7148-1 mount, at 120, 160, and 200 cps



120 cps

160 cps

200 cps

(d) Light trace with Lord shear-type J-8350-7 and -8 mount, at 120, 160, and 200 cps

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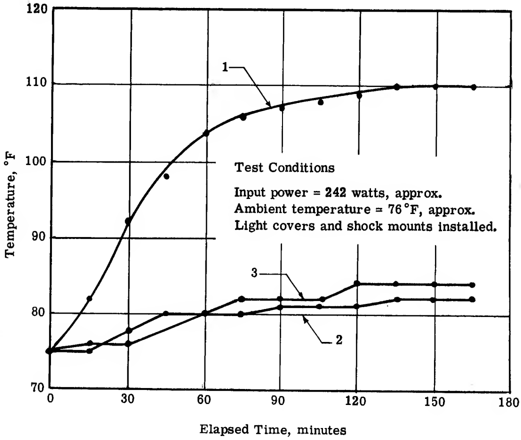

Fig. 4-3 — Recorder temperature rise during 3-hour operating period

1. Thermocouple on top surface of deflection and logic assembly
2. Thermometer near capstan
3. Thermometer on outer surface of top cover at point above capstan

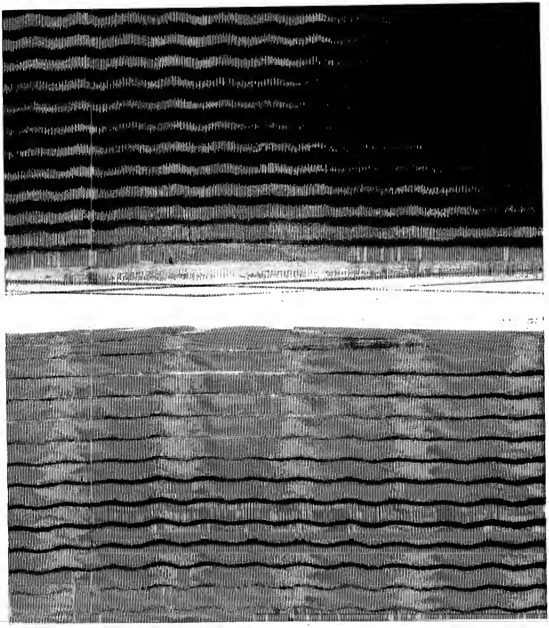

Fig. 4-4 — Typical moire pattern caused by nonuniform motion of film in recorder

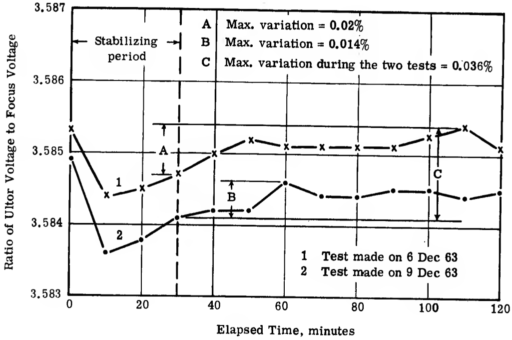

Fig. 4-5 — Change in ratio of ultor voltage to focus voltage as a function of operating time

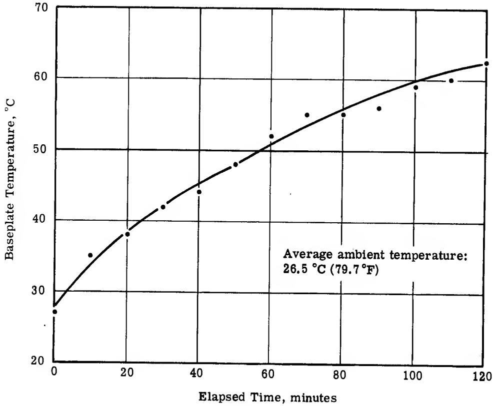

Fig. 4-6 — High voltage power supply baseplate temperature as a function of operating time

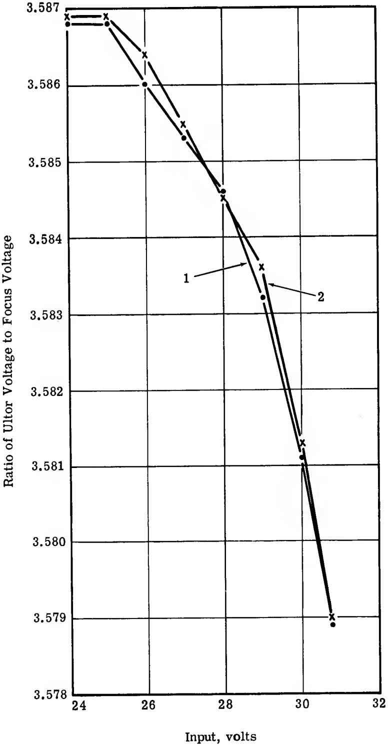

Fig. 4-7 — Changes in ratio of ultor voltage to focus voltage as a result of line and load variations

1 No load (ultor and focus current = 0)
2 Full load (ultor current microamps; focus current = 215 microamps)

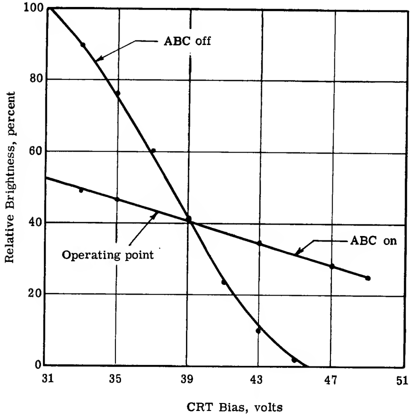

Fig. 4-8 — Relative CRT brightness as a function of bias voltage

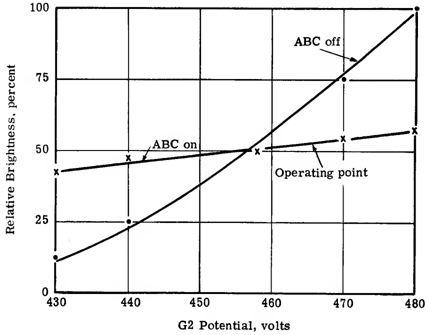

Fig. 4-9 — Relative CRT brightness as a function of voltage on G2 electrode

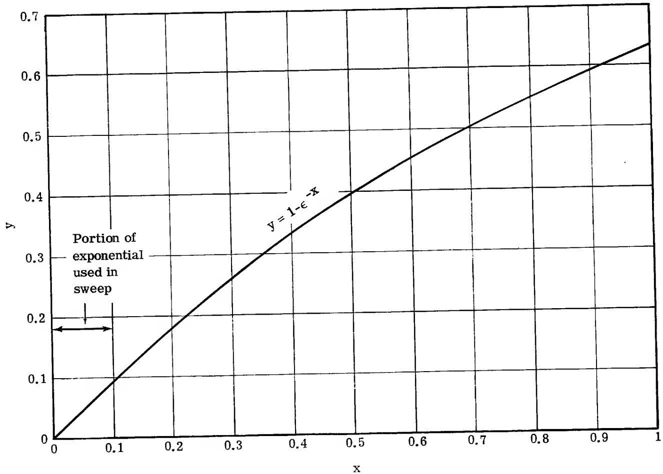

Fig. 4-10 — Plot of exponential function, $y = 1-\epsilon^{-x}$, showing portion used in recorder sweep

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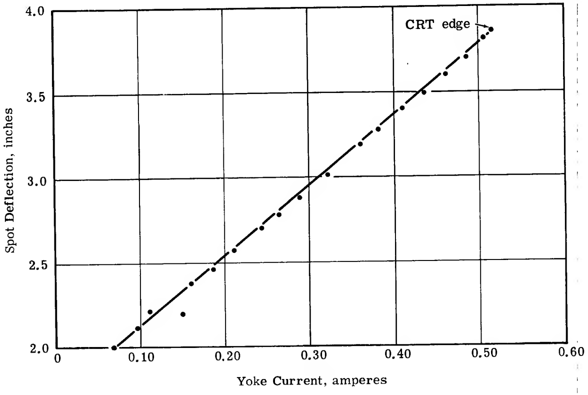

Fig. 4-12 — CRT spot deflection as a function of dc current input to deflection yoke

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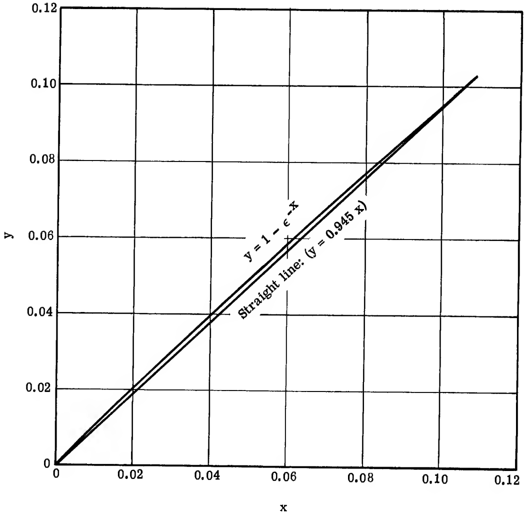

Fig. 4-11 — Sweep circuit waveform compared with a straight line

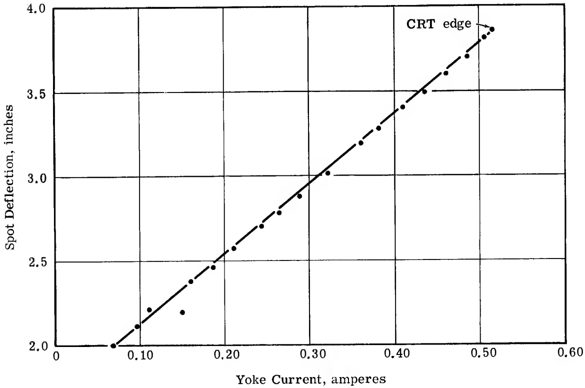

Fig. 4-12 — CRT spot deflection as a function of dc current input to deflection yoke

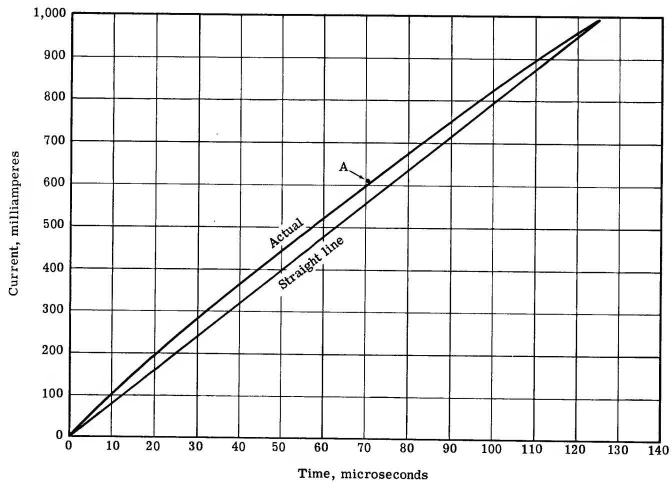

Fig. 4-13 — Deflection yoke current as a function of time for triangular current waveform

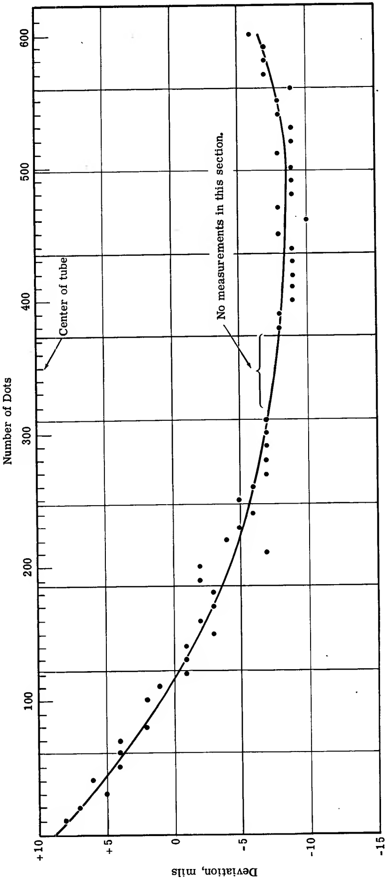

Fig. 4-14 — Sweep velocity variations from perfect linearity

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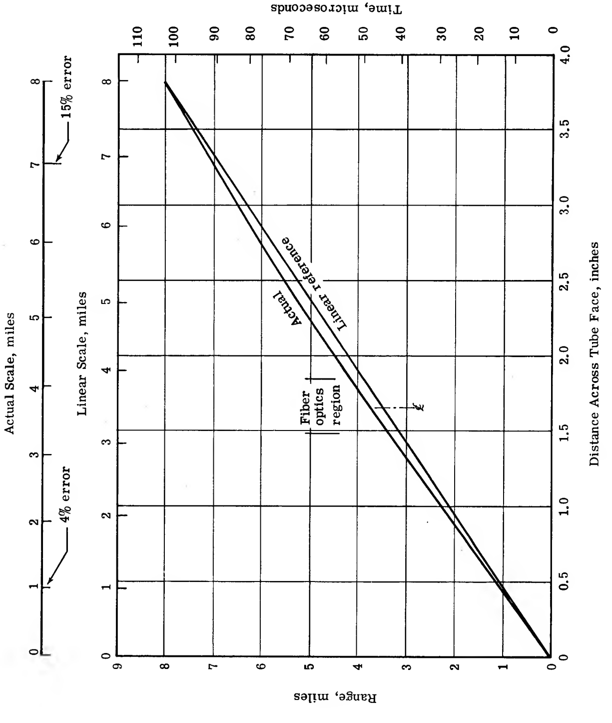

Fig. 4-15 — Triangular sweep distortion

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